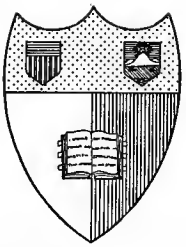

MEMOIRS OF THE GEOLOGICAL SURVEY, SCOTLAND.

THE GEOLOGY

OF

BEN WYVIS, CARN CHUINNEAG, INCHBAE AND THE SURROUNDING COUNTRY,

INCLUDING

GARVE, EVANTON, ALNESS AND KINCARDINE.

(EXPLANATION OF SHEET 93.)

By

B. N. PEACH, LL.D., F.R.S.; THE LATE W. GUNN;
C. T. CLOUGH, M.A.; L. W. HINXMAN, B.A., F.R.S.E.;
C. B. CRAMPTON, M.B., C.M.; AND E. M. ANDERSON, M.A., B.Sc.

WITH

PETROLOGICAL CONTRIBUTIONS

BY

J. S. FLETT, M.A., D.Sc.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY.

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SUMMIT OF MEALL A' GHRIANAIN, looking north to Beinn a' Chaisteil.

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PREFACE.

THE district described in this Memoir includes, in the east, part of the tract of low-lying fertile ground which adjoins the shores of the Cromarty and Dornoch Firths, but the whole western half of the Sheet is a mountainous region devoted almost entirely to sport. Until the survey of the area was commenced little information was available regarding the structure of that part of the country which consists of crystalline and metamorphic rocks. The existence of the coarse granitic gneiss of Inchbae was known, but its great extension and the remarkable features of the contact-altered zone of sediments around it were quite unsuspected.

The officers of the Geological Survey have not hitherto undertaken the description of so large an area of crystalline schists and gneisses belonging mainly to the Moine Series, and lying to the north of the Great Glen. It is therefore fortunate that the geology of this Sheet provides a key to some of the most important problems of the Moine Schists and Gneisses. The work of the Survey has proved that the augen gneiss of Inchbae and Carn Chuinneag was a great intrusive mass of granite (with subordinate masses of gabbro, etc.), and that the Moine rocks around it were originally shales, sandstones and marls of ordinary sedimentary types. By the action of the granite-intrusion the adjacent sediments were converted into hard banded splintery hornfelses. At a later period the whole district was involved in folding and earth-movement which changed the granite into a gneiss and at the same time transformed the sediments, where they were unaffected by the granite, into mica schists, granulites and other metamorphic rocks. But the contact-altered rocks had been so indurated as to offer considerable resistance to these movements, and have consequently, in many places, retained the characters which they possessed before the movements took place. It has been found possible, both in the field and with the microscope, to trace the stages by which igneous and sedimentary rocks pass into crystalline schists and gneisses. For this reason the district described in this Memoir is of especial interest not only to students of the geology of Scotland, but to all who are interested in the problems of metamorphism; as an illustration of "dynamo-metamorphism" on a large scale it could hardly be surpassed. Somewhat similar phenomena have been observed by Mr. Barrow in the neighbourhood of Ben Vuroch, Perthshire, and are described in the Memoir on Sheet 55 (Scotland).

Another point of interest is the discovery of tinstone for the first time in Scotland. It was found on the north-west shoulder of Carn Chuinneag, in masses of magnetic iron ore occurring in the granitic gneiss.

The survey of this Sheet was commenced in 1883 and completed in 1904. The late Mr. Hugh Miller, jun., mapped most of the Old Red Sandstone, and the late Mr. W. Gunn surveyed the district around Meall a' Ghrianian. The greater part of the western half of the map is the work of Dr. Peach, Mr. Clough, Mr. Hinxman, Dr. Crampton and Mr. E. M. Anderson, but a small portion near the western margin was surveyed by Mr. Pocock, who has not contributed to this Memoir. All the other surveyors, with the exception of Mr. Miller, are responsible for the description of the districts they surveyed. Dr. Flett has contributed chapters on the petrology, and the rock analyses were made by Dr. Pollard and Mr. Radley. Mr. Clough acted as district geologist in charge of the field work from 1902 to 1904 and has edited the Memoir. The photographs of scenery and rock-structures were taken by Mr. Lunn, and the photomicrographs by Mr. T. C. Hall. Plate XII. has already appeared in the *Geological Magazine*, and is reproduced here by permission of the Editor.

J. J. H. Teall, *Director*.

Geological Survey Office,
28, Jermyn Street, London,
13*th January*, 1912.

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THE GEOLOGY OF BEN WYVIS, CARN CHUINNEAG, INCHBAE, ETC.

CHAPTER I.

INTRODUCTION.

Area and Physical Features.

This Sheet of the Geological Survey of Scotland represents an area of 432 square miles, the whole of which,—with the exception of a small part of Sutherlandshire, less than two square miles in extent, on the north side of the Dornoch Firth,—falls within the county of Ross. The district under consideration extends from Creich in Sutherlandshire, in the north-east, westwards to the Freevater Forest at the head of Glen Carron, and in the south from the head of Loch Luichart eastwards to the Cromarty Firth.

The wild region of mountain top and undulating peaty moorland, traversed by deep glens and river valleys (see Plate II.), that forms the greater part of the area under description, has been carved by the slow forces of denudation out of an elevated plateau or series of plateaux, relics of which still exist in different parts of the district (see Frontispiece). The least dissected portion of this ancient tableland is found in the north-western quarter of the map, near the upper part of Strath Vaich and to the north of Gleann Beag and part of Gleann Mor. The average height of the plateau is about 2000 ft., but it rises to the north-west, where the highest summits are Am Faoch-agach, 3120 ft., Carn Ban, 2762 ft. and Bodach Mor, 2689 ft. The flat tops of Beinn a' Chaisteil, Meall a' Ghrianain, and Beinn Tharsuinn on the north side of Strath Rusdale, may all be taken to represent portions of the tableland. It may be mentioned that this plateau does not continue for any considerable distance northwards into one-inch map 102. In this direction it ends in a tolerably well defined steep slope which does not correspond to any stratigraphical boundary, and overlooks a wide expanse of lower ground, rarely exceeding 1300 or 1400 ft. in height, that stretches to the north beyond Strath Oykel and Loch Shin.

The mountain *massif* of Ben Wyvis, which rises between the valley of the Black Water and Loch Glass, and forms the dominant feature of Easter Ross, perhaps represents another and higher plateau. The mean elevation of the flat-topped summit is at least 2500 ft., while the five principal tops or culminating points of the plateau all reach an altitude of 3000 ft., the highest cairn being 3429 ft. above sea-level. The mountain rises towards the west in a steep and almost

unbroken escarpment, nearly six miles in length, which coincides with the main outcrop of the pelitic gneiss in this region, while the eastern side of the range has been carved into a series of precipitous rocky corries and deep glens drained by the head waters of the Allt nan Caorach.

A lower tract of country fringes the southern shore of the Kyle of Sutherland in the north-east corner of the map, and near Kincardine extends inland for a distance of three miles. This plateau, which has a mean elevation of 800–900 ft., forms part of the comparatively low platform which can be traced almost continuously around the northern and north-eastern coasts of Scotland.

Drainage Systems, Lochs, Rainfall.

The central and south-eastern region is drained by the Glass, the Alness and other smaller rivers flowing into the Cromarty Firth; the northern third of the map lies for the most part within the basin of the Carron, but a small area in the north-west corner belongs to that of the Oykel; the remaining portion of the Sheet in the west and south-west is included in the drainage area of the Black Water and the Conan.

A feature common to the principal streams that flow south-eastwards into the Firth of Cromarty is the unequal gradient of their courses, a completely or partially graded portion of the river valley being succeeded, sometimes more than once along the same stream, by a steep fall.

In the case of the Glass and Alness Rivers the flat portions of the valley have been further deepened by the erosive action of ice, and the portions below the base level of river erosion are now occupied by the waters of Loch Morie and Loch Glass. The barrier above which the grading of these two rivers and, in a lesser degree, of the Strath Rusdale stream, has taken place, is formed by the outcrop of the Old Red Sandstone conglomerate. A second barrier higher up the Alness River is due to the high ground formed at the junction of the augen gneiss and the Moine sediments, and separates the flat drift-filled valley of the Abhuinn na Glasa from the steep fall immediately above Loch Morie.

The Glascarnoch River, from the point where it enters the map to Aultguish Inn, meanders sluggishly through an extensive alluvial flat which marks the side of a former loch, fully five miles in length. The silting up of this loch has been mainly effected by the material brought down by the tributary streams that drain the drift-covered slopes on either side of the valley. The rock barrier to which this loch was due crosses the stream immediately below Aultguish Inn.

Strath Vaich offers another example of a gently graded valley, the fall of the stream, especially in the upper part of the glen below Loch Toll a' Mhuic, being very slight. L. W. H.

The height of the watershed between Strath Vaich and Gleann Mor near Deanich Lodge does not exceed 1250 ft., being only about 300 ft. above the level of the adjoining part of the Gleann Mor burn. Gleann Mor is a narrow glen, and it may perhaps be supposed that it is of comparatively recent origin, and has captured the drainage of

considerable tracts which in earlier times drained southwards into Strath Vaich. It should, however, be pointed out that on the north side of Gleann Mor there is no valley which can be conveniently regarded as the continuation of Strath Vaich, and that in the burn south-east of Deanich Lodge a strong crush line is seen striking for the low ground at the head of the strath. This line of weakness may greatly have facilitated the work of subaerial denudation.

Near and for some distance above Deanich Lodge, the Gleann Mor stream is much more sluggish than below, and appears to be traversing the site of a silted-up loch about a mile long. The long axis of this old loch and of Gleann Beag, to the west, is nearly in the same direction as Gleann Mor, and almost at right angles to Strath Vaich.

C. T. C.

The River Glass, in the lower part of its course above the village of Evanton, flows through the well known gorge of the Black Rock of Novar. This remarkable chasm has been eroded in the pebbly sandstones and conglomerates of the Old Red Sandstone, and is an extreme example of the deep and narrow gorges cut by most of the rivers of the East Coast, where they breach the outcrops of the harder members of that formation. From a careful series of measurements carried out by Mr. Hugh Miller, jun., it was found that the depth of this chasm to the surface of the water varied from 100 ft. in the deepest portion to 70 ft. at the upper end; the width at the surface from 17 to 40 ft., with an average of 20–25 ft. The potholes seen at different levels on both sides of the chasm show that it is entirely due to the agency of running water, the eroding power being supplied by the detritus derived from the drift-filled portions of the upper valley. The gorge of the Black Rock is entirely post-glacial in origin. The pre-glacial course of the river can be traced, as pointed out by Mr. Miller,* to the south of the upper end of the present channel, and is indicated by the hollow, almost filled with boulder clay, that crosses the hillslope to the north of the farm of Upper Park.

The Skiack River above Swordale flows through a wide pre-glacial valley deeply filled with boulder clay, through which the stream is now cutting or has already cut down to the original rock floor. The waterfalls on the river immediately above the mouth of the small burn at Clare indicate the position of a former rock barrier, above which the river winds through a series of alluvial flats which may represent the sites of earlier lake basins.

The upper course of the Alness River in the Kildermorie Forest is also through a wide drift-filled valley, but for half a mile above the Lodge it is flowing over rock. Below Loch Morie the river valley has evidently been in a large measure determined by the Loch Morie fault, and in the neighbourhood of Ardross Castle has been eroded along the faulted junction between the conglomerates and the softer shales and flagstones. The bed of this stream, like that of others in the area, is filled in places with huge rounded boulders of augen gneiss and other rocks washed out of the drift deposits.

The principal lochs within the area are Loch Morie, on the Alness River, and Loch Glass, on the stream of that name, both situated close

* 'The Black Rock of Novar,' *Trans. Scien. Soc., Inverness*, 1887, vol. iii. p 308.

together in the centre of the map. The western and larger portion of Loch Luichart also enters within the southern margin of the Sheet.

The waters of Loch Morie cover an area of nearly a square mile, and are derived from a drainage area over thirty-five square miles in extent. The loch is two and a third miles in length with a mean breadth of half a mile, and presents the form of a simple basin with a maximum depth of 270 ft. in the centre. The stream that issues from the loch flows over a rock barrier, and the loch undoubtedly lies in a rock basin, determined in some degree by the powerful fault which passes through it in an oblique direction.

Loch Glass, four miles in length and half a mile in breadth, is the deepest loch within the drainage basin of the Cromarty Firth, maximum soundings of 365 ft. having been obtained at a point towards the north-eastern shore rather nearer the north-west than the south-east end of the lake. There are considerable drift deposits around the foot of the loch, and traces of terraces along the southern shore to the east of Culzie Lodge indicate a former higher level of its waters. The River Glass flows over a ridge of conglomerate at the Eileanach falls, two miles below the foot of the loch, at an elevation of 650 ft., and as the surface of the loch is 713 ft. above datum level, it follows that the deepest part of the basin lies at an elevation of 348 ft., or 302 ft. below the level of the rock barrier.

The bathymetry of Loch Luichart is fully discussed in the explanation accompanying Sheet 83 of the Geological Survey. The largest and deepest of the three basins found on the irregular floor of the loch comes within the present map, and the maximum depth of 164 ft. is found about a mile and a half from the western end. Loch Luichart is a true rock basin with a rock barrier at its outlet.*

Of the numerous smaller lochans scattered over the Sheet, some, such as Loch Bealach Culaidh in the Wyvis Forest, can be shown to be true rock basins, but most are entirely or partially held in by drift deposits. L. W. H.

The average annual rainfall is not excessive in the comparatively low eastern and south-eastern portions of this map, but in the west and north-west it is much greater. Mr. Andrew Watt, the Secretary of the Scottish Meteorological Society, has kindly furnished the rainfall statistics for the seven years 1901–1907, for the rain-gauges stationed at Evanton (Swordale House) and Ardross Castle. These are shown in the following table :—

	Evanton.	Ardross Castle.
Height in feet	520	450
Rainfall in inches in 1907	25·40	38·76
„ 1906	35·90	48·72
„ 1905	33·90	41·21
„ 1904	26·40	34·86
„ 1903	41·60	54·20
„ 1902	22·50	33·84
„ 1901	29·30	38·81

* Much of the above information has been taken from a paper on the 'Bathymetrical Survey of the Freshwater Lochs of Scotland' (under the direction of Sir John Murray and Mr. Laurence Pullar), published in the *Scottish Geographical Magazine* for September 1905.

In the western portion of the map no rain-gauges have been set up, but at the rain-gauge at Loch Droma, about two miles west of Strathderie, and at a height of about 900 ft., the annual rainfall for the same seven years varied from 58·02 to 109·93 in. The average fall came to 83·63 in. C. T. C.

Tabular List of Formations.

The following list shows the different geological formations and rock groups shown in the map. The chief formations, indicated by the names outside the brackets, are placed in order of age, the youngest at the top, but the minor groups within the brackets are not necessarily so arranged.

Pleistocene and Recent.
- Peat.
- Freshwater Alluvia, largely represented by River Terraces at different levels.
- Marine Alluvia, including Raised Beaches at three different levels, the highest about 85 ft.
- Fluvio-glacial Sands and Gravels.
- Morainic Drift.
- Boulder Clay.

Old Red Sandstone.
- Middle or Orcadian.
  - Shales and Flagstones.
  - Sandstones.
  - Conglomerate and Breccia.

Newer Intrusive Igneous Rocks.
- Scyelite. Peridotite.
- Dolerite.
- Lamprophyre and Mica Trap.
- Aplite.
- Granite.
- Pegmatite.

Older Intrusive Igneous Rocks.
- Igneous Complex of Carn Chuinneag and Inchbae.
  - Hornblende Schist in Dykes newer than the Granitic Gneiss.
  - Granitic Gneiss, including Augen Gneiss and Riebeckite Granulite.
  - Garnetiferous Albite Gneiss with Magnetite and Tinstone.
  - Diorite, Quartz Diorite, Epidiorite representing Gabbro, Pyroxenic and Hornblendic Gneisses, Hornblende Biotite Schist. Consolidated before the Granitic rocks.
- Sills and Dykes of Epidiorite, Hornblende Schist and Garnetiferous Amphibolite, in the Moine Series.

Moine Series.
- Pelitic Gneiss and Schist representing argillaceous sediments, Pelitic Hornfels, Siliceous (Psammitic) Schists and Quartz Biotite Granulites.

Lewisian Gneiss.
- Acid and Hornblendic Gneiss.

Distribution and Relations of the Formations.

The rocks referred to the Lewisian Gneiss occur only in a few small patches in the south-west portion of the map, where they appear to come out from below the Moine schists. The only Scottish rocks which can at present with perfect confidence be classed with the Lewisian Gneiss are found on the west side of the Moine thrust, and are overlain unconformably by the Torridonian and Cambrian rocks. Other masses of gneissose rock, including those in the small patches in this map, which occur on the east side of this thrust have, however, a striking lithological resemblance to the Lewisian Gneiss further west, and are therefore classed with it.

From evidence obtained in adjoining maps, it is believed that the Lewisian Gneiss is an older formation than the Moine Series, and is separated from it by an important unconformity. Evidence in support of this view has been obtained, for instance, in the Strath Conan and Strath Farrar area, in one-inch map 82,* in parts of which a rock having all the appearance of a sheared conglomerate is sometimes found resting in isolated patches on the Lewisian Gneiss. It is to be remembered, however, that both this Lewisian Gneiss and the Moine rocks have been affected by intense dynamo-metamorphism, which has often developed a common foliation, and has helped to obliterate the great differences, both in lithological character and tectonic structure, which may once have existed between them.

The Moine schists form a great metamorphic series which occupies most of the area between the Old Red Sandstone of the north-east coast of Scotland and the Moine thrust, which strikes N.N.E. nearly through the middle of the next one-inch map to the west. They are no doubt paraschists or paragneisses, representing a great sedimentary series originally composed in the main of sandstones, pebbly grits and sandy shales, which has been greatly folded and altered. In original character they probably bore considerable resemblance to the Torridonian rocks west of the Moine thrust, and it has been supposed by Dr. Peach and others that they are altered representatives of these rocks.† But this correlation cannot yet be regarded as proved.

A broad band of pelitic or, more strictly, semipelitic sediment belonging to the Moine Series is found most of the way along the margin of the largest granitic mass, that of Carn Chuinneag. This band is of special interest, as it is partly composed of masses of hornfelsed rock (Plate XII.), which have never been deformed or sheared, and enable us still to picture clearly the dark sandy muds and thin gritty laminæ from which most of them were formed. These completely undeformed sediments lie in the heart of the Moine schists, as much as twenty-five miles east of the Moine thrust, and there is clear evidence that they are part and parcel of the same geological formation as these schists—schists which are for the most part in such a highly altered condition that they might be taken as types of the rocks once called primary or primitive, under the impression that they had been

* Dr. B. N. Peach, *Summary of Progress of the Geological Survey* for 1904, p. 75. L. W. Hinxman, C. B. Crampton, E. M. Anderson and R. G. Carruthers, *Summary of Progress of the Geological Survey* for 1905, pp. 103–109.

† *Annual Report of the Geological Survey* for 1892, p. 262.

THIN GRANITIC INTRUSIONS IN MOINE SERIES IN GARBH ALLT.

formed, much as we now see them, in the early ages of our planet, under very peculiar conditions which have never since recurred.

Thanks to this evidence, we can now assert with confidence that the Moine schists have been formed out of sediments which differed in no essential particular from the sandy shales and clays of recent formations. The injection of the great igneous masses of Carn Chuinneag and Inchbae has, by the alteration induced, so welded the sedimentary laminæ together, that, in the subsequent earth movements which affected the region, many parts moved as units, and escaped all that sharp isoclinal folding and molecular change which resulted in the manufacture of the surrounding schists.

The Older Intrusive Igneous rocks are represented by many types of orthogneiss, including, as they do, all those which were intruded into the Moine schists before the latter were foliated. The Newer Intrusions comprise, on the other hand, those which have been injected after these schists were already foliated and essentially in their present condition. This classification can in most cases be carried out satisfactorily, but there are a few bands the correct place of which is in some doubt.

The Older (foliated) Granite forms various crops which have a general N.N.E. strike, and stretch with but slight interruptions from Loch Luichart to the River Carron. The crop farthest to the north-east is much larger than all the rest combined. It is about eleven miles long and five broad, and may be named the Carn Chuinneag mass, from its highest hill. The boundary in some areas is of a very complicated character, thin veins of granite extending far beyond the main area (Plate III.). The north-western portion of the mass includes near the margin a considerable proportion of basic rocks, consisting chiefly of diorite, epidiorite (representing gabbro) and hornblendic gneiss or hornblende schist. These basic rocks appear to be the first consolidated portions of the magma, and have been pierced in a most complicated manner by later acid granitic veins. Besides the early basic portions of the magma, various later dykes are also found, now in the form of hornblende schist, which in turn cut the foliated granitic rocks.

Sills and dykes of epidiorite, hornblende schist, etc., are not uncommon in the Moine schists, in areas which are often far distant from the Carn Chuinneag complex. The age of these intrusions in relation to this complex has not been determined. They are, however, very frequently in a thoroughly schistose condition, and are therefore placed with the Older Igneous Rocks.

The Newer Igneous Rocks are mainly represented by the Fearn or Corriefearn granite, which occupies an area of about 12 square miles in the north-eastern corner of the map. Its long axis extends in a N.N.W. direction, and is thus in striking contrast to those of the chief masses of the Older Granite.

There is no doubt that the Newer Granite and some of the Newer Dykes were intruded before the deposition of the Middle Old Red Sandstone found in the district, but it is not certain that all these dykes were. In the neighbouring one-inch map 83 a lamprophyre dyke has been intruded into the Old Red Sandstone.

Between the period of the production of schistosity or foliation in the Moine schists and that of the deposition of the Old Red Sandstone,

an immense interval of time must have elapsed. The interval is represented in this area only to a small extent, partly by the introduction of pegmatites in the Moine rocks, partly by the intrusion of the Newer or Fearn Granite, in the north-east corner of the map, and partly by the great denudation which wore down the schistose area into hill and valley prior to the deposition of the Old Red Sandstone.

The various broad pegmatites which have been introduced into the Moine rocks, in places at a considerable distance from any granitic mass, are never sheared, and they are therefore placed with the Newer Igneous rocks, though it is probable that they are quite independent of and much older than the Fearn granite. They are further described in Chapter II., in treating of the different districts where they are found.

The Old Red Sandstone extends along the eastern margin and the eastern half of the southern margin of the map, forming a triangular area between the Kyle of Sutherland and the Cromarty Firth, and includes also the low ground on both sides of the latter arm of the sea. There are also various outliers in the western part of the map. One of these, on Meall a' Ghrianain, reaches a height of 2531 ft., and it seems, therefore, quite possible that at one time the whole of the schists in the map may have been covered by the Old Red Sandstone.

Another immense interval of time elapsed between the Old Red Sandstone and the Glacial periods. In the adjoining one-inch maps 103, to the north-east, and 92, to the west, Mesozoic rocks are found which represent part of this interval. The Tertiary igneous rocks of Skye represent another later portion. C. T. C.

Scenery in relation to Geology.

The denuded tableland of metamorphic and igneous rocks referred to near the beginning of this chapter affords many instances of differential erosion due to variations in the nature and arrangement of the rocks. In the areas occupied by the schists and gneisses of the Moine Series the pelitic gneiss usually forms the most rugged ground, and where rapidly interfolded with the siliceous granulites tends, by unequal weathering, to produce highly diversified features. The more massive siliceous rocks, on the other hand, more readily give rise to smooth and rounded outlines. L. W. H.

The Older Granite does not usually form high ground, but reaches an altitude of 2749 ft. on Carn Chuinneag and of nearly 2200 ft. on Creag Ruadh. In certain districts its greatest elevation is found along the marginal junction with the Moine sediments. In the central part of the map this Older Granite gives rise to a wide stretch of gently undulating ground, largely covered with peat, that extends northward from Strath Rannoch to the southern slopes of Diebidale. The coarser-grained type of rock forms rounded hills such as Carn Breac, and weathers into large blocks, while the peaks of Carn Chuinneag are composed of a finer-grained variety which produces scree slopes of somewhat smaller fragments. The enormous rounded boulders derived from the coarser augen gneiss are conspicuous in many parts of the district. C. B. C.

The homogeneous nature of the Newer Granite causes it to weather evenly into smooth flat-topped hills with gentle slopes, which are often covered to a considerable depth with rock disintegrating in place into sand.

The Old Red Sandstone strata of the coastal belt give rise to more varied topographical features. The coarse basal breccia forms the abrupt steep-sided bluffs of Struie Hill and Meall an Tuirc, whose component strata may originally have been deposited against a steep cliff or face of the schistose rocks, since removed by denudation. To the higher pebbly conglomerate is due the rampart of Cnoc Duchaire and Cnoc Fyrish, which rises steeply from the low sandstone area along the shores of the Firth of Cromarty, while the hollow between Cnoc Ceislein and Bendeallt has been eroded in the softer shales and mudstones, which have also produced the gently rounded hills and soft flowing outlines of upper Strath Skiack.

The three great lines of fault which traverse the district in different directions have also been more or less important factors in determining the surface configuration of the country. The Strathconan fault, which has been traced for many miles to the south-west, enters the map at the head of Loch Luichart and has probably been the cause of the abnormal depth that is found close up to the head of that loch, the shattered rock having been more readily removed by subsequent glacial action. The band of crushed rock seen on the Glascarnoch River below Aultguish Inn, probably belongs to a branch of this fault which runs north and N.N.W. to the corner of the map, and has apparently determined the valleys of Strath Vaich and Coire Mor. A portion of the straight N.N.E. course of Glen Diebidale has also been eroded along the line of a powerful fault which is believed to represent a more direct continuation of the Strathconan and Loch Luichart fault. Another important fault has defined the upper part of the valley of the Alness River, while the hollow of Loch Morie, which is crossed obliquely by the fault, is also no doubt due in some degree to this line of weakness. Further to the west the displacements produced by this Loch Morie fault have interrupted the continuity of the junction of the augen gneiss with the hardened sediments, and have shifted it westwards for a distance of two miles or more. L. W. H.

Summary of Geological Literature.

The old metamorphic rocks within this one-inch map do not seem to have received much attention from any of the older writers. Dr. John MacCulloch, in his "New Geological Map of Scotland," coloured all of them as gneiss, and Prof. Nicol did the same in his much smaller "Geological Map of Scotland," published in 1858. Neither of these authors showed any of the foliated granitic masses.

In 1857, Hugh Miller, sen., in his "Rambles of a Geologist," described the structure of a boulder of granitic gneiss lying at the edge of the Auldgrande (near Evanton). He supposed it to have been transported glacially from the west, but does not say he had seen the rock *in situ*. As far as is known, Mr. William Jolly was the first writer who called public attention to the peculiar parallel foliated structure in the Inchbae granite. This he did in the Fifth Report

of the Boulder Committee of the Royal Society of Edinburgh,* wherein he notes that the distinctive feature in this granite is "the existence of lenticular pieces of dark mica, arranged throughout its mass in pretty regular layers, which give the rock somewhat of the general appearance of a stratified rock."

It does not appear to be till a few years later that the greater granitic mass of Carn Chuinneag was publicly referred to in a definite manner. This was by Mr. William Morrison, again in a Report of the Boulder Committee of the Royal Society of Edinburgh,† who states that Carn Chuinneag and Carn an Lochan are both entirely composed of granite.

The Newer Granite of Fearn is indicated in both the maps, already referred to, of MacCulloch and Nicol. Being so near the coast and an important road to the north, it would naturally attract attention at an early date.

One of the earliest references to the Old Red Sandstone strata of the portion of Easter Ross included in this map is contained in the paper by Sedgwick and Murchison, read before the Geological Society of London in 1828, and published in their Transactions in the year 1835.‡ The authors give a detailed description of the rocks exposed along the courses of the Allt Grant or River Glass and the Alness River. They recognise an upper and a lower or basal conglomerate, separated by a series of bituminous and calcareous shales and flagstones with some red and greenish marls. The basal conglomerate is correlated with that of the Maiden Pap in Caithness, and the close resemblance of the shales and flagstones to many of the lower beds associated with the bituminous shales of that county is pointed out. They also show that the Old Red Sandstone strata on either side of the Cromarty Firth lie in a synclinal fold, whose eastern limb is bent sharply up against the older rocks of the Sutors of Cromarty. Reference is also made to the great alluvial terraces of sand in the upper parts of Glen Glass.

Hugh Miller, sen., in his "Rambles of a Geologist," has given a vivid description of the chasm of the Auldgrande, now generally known as the Black Rock of Novar. He speculates as to the origin and history of the fissure, and refers incidentally to the drift and carried boulders of the neighbourhood, making special mention of the large boulder of granitic gneiss which has been already alluded to on the preceding page.

In his valuable paper on the Old Red Sandstone of Western Europe,§ Sir Archibald Geikie refers to the work of previous observers in the northern basin of Old Red Sandstone, to which he has given the name of Lake Orcadie. He states that while the area occupied by this formation was shown with tolerable accuracy on the map published by Ami Boué in 1820, the first attempt to work out the structure of the region was that made by Sedgwick and Murchison in 1827 (*vide supra*). Sir Archibald Geikie, in his description of the area between

* *Proc. Roy. Soc. Edin.*, 1878–1879, vol. x. p. 178.

† *Proc. Roy. Soc. Edin.*, 1880–1881, vol. xi. p. 743.

‡ 'On the Structure and Relations of the Deposits contained between the Primary Rocks and the Oolitic Series in the North of Scotland,' *Trans. Geol. Soc.*, 2nd series, vol. iii. p. 125.

§ 'On the Old Red Sandstone of Western Europe,' *Trans. Roy. Soc. Edin.*, vol. xxviii. p. 345.

Inverness and the Dornoch Firth (p. 444), quotes the observations and conclusions of these authors as given in their paper, to which reference has been already made. He also records the discovery of the fish-beds near Edderton by the Rev. Dr. Joass, of Golspie, and gives particulars of the occurrence and genera of the fish remains, as communicated to him by that gentleman.

C. T. C., L. W. H.

CHAPTER II.

LEWISIAN GNEISS AND MOINE SCHISTS.

In this chapter we shall first describe the Lewisian Gneiss, which, as already stated in Chapter I., is believed to be the oldest formation in the district. After that, we shall pass on to the second part treating of the Moine *schists*, leaving for a subsequent chapter the full description of those Moine rocks which are in a hornfelsed condition, and have escaped being made into schists.

LEWISIAN GNEISS.

Rocks of Lewisian type occur in two separate areas near the south-western margin of the map. The more westerly outcrop extends from the southern shore of Loch Luichart to the edge of the map, and forms the north-eastern extension of a mass of acid and hornblendic gneiss which will be described and shown in section in a forthcoming Explanation accompanying Sheet 83. It occupies the core of a compound anticlinal fold which pitches out towards the north-east, the last or most northerly fold being also truncated by a fault by which the gneiss is brought against the overlying siliceous Moine schist. The other area is found on the hillslope about a mile and a quarter north-east of Garve. Here the gneiss is seen in a series of small exposures, and occurs in lenticular masses upon the crests of anticlinal folds, surrounded by siliceous Moine schists. These inliers comprise both basic and acid hornblende gneisses and biotite gneisses, together with amphibolites and foliated peridotites, which probably represent original basic and ultrabasic dykes. B. N. P.

Certain highly felspathic acid gneisses which are exposed in the two northern tributaries of Allt a' Gharbh Bhaid, on the west side of Ben Wyvis, should also probably be referred to the Lewisian Gneiss. These will be shortly mentioned again in describing the Moine schists.

L. W. H.

MOINE SCHISTS.

INTRODUCTION AND CLASSIFICATION.

The schists and gneisses forming the Moine Series have a very wide distribution in the Northern Highlands. In the present one-inch map they include, in conjunction with hornfelsed rocks of the same series, the whole area excepting that occupied by the intrusive igneous rocks and by the Old Red Sandstone and the Lewisian above described.

There is ample proof within the limits of this Sheet that these rocks of the Moine Series are the metamorphosed equivalents of sediments of varying arenaceous and pelitic or semipelitic composition, though

their geological age is still undetermined. A semipelitic is much more common than a pelitic character, but, in the general descriptions to follow, the term "pelitic" has often been used for brevity. Altered representatives of pure limestones are absent from this area, but thin bands which contain zoisite and hornblende, and accompany the pelitic gneisses and hornfels, are probably altered impure calcareous deposits.

The gneisses of pelitic or semipelitic origin form subordinate bands in the predominant quartzose schists (Plate XII.). The most important of the former can be traced for many miles along the crop, shown in the map, and afford the best means of working out the structure of the country and the succession of strata.

Four groups have been separated in the Moine rocks in this Sheet. They are shown in the following list, in which the group supposed to be the newest is placed at the top :—

4. Pelitic mica schist and hornfels.
3. Quartzose schists and subsidiary micaceous bands.
2. Pelitic gneiss or garnetiferous muscovite biotite gneiss.
1. Quartzose schists with subsidiary micaceous bands.

The chief crop of the lowest group (1) is found in the eastern part of the map, where it forms a belt next to the Old Red Sandstone, and extends from the east side of Little Wyvis north-eastwards nearly to Struie Hill. As far as known, it does not include any bands of dark biotite schist, such as are so frequently met with in the higher quartzose group (3), and many beds are very siliceous, poor in mica, and weather white, like quartzite. The lower pelitic gneiss (2) forms a broad belt following the western margin of the chief crop of the lower siliceous group (1), extending from Strathgarve to the north-east corner of the Sheet at Easter Fearn. Evidence is given in the detailed description, to show that the pelitic gneiss of this belt overlies the rocks of the siliceous group to the east (1).

Another belt of pelitic gneiss, which is considered from its lithological character to belong to the same group (2), has been traced from the western end of Loch Luichart in a N.N.W. direction to Coire Mor, in the north-west corner of the map. This belt has been traced further, in Sheet 102, to the north, and has been found to bend round and enter one-inch map 93 again, near Alladale Lodge. The evidence in the latter area suggests that this belt is the denuded top of an upfold of the pelitic gneiss, and this inference is strengthened by the similarity, in many places, of the rocks in the supposed overlying quartzose group (3) on each side of the belt.

The rocks of this quartzose group (3) occupy a wide continuous area between the belts of pelitic gneiss above referred to. They are specially marked by the occurrence of a band of pebbly schist or schistose grit, and by numerous thin bands of dark biotite schist. The pebbly schist contains well preserved pebbles of quartz and felspar, and others of igneous and sedimentary origin, which will be more fully described in the sequel. Their preservation is, perhaps, chiefly owing to their original large size. In the other siliceous schists the remains of pebbles are smaller, but can still frequently be recognised, together with structures which have a very close resemblance to bedding and false-bedding.

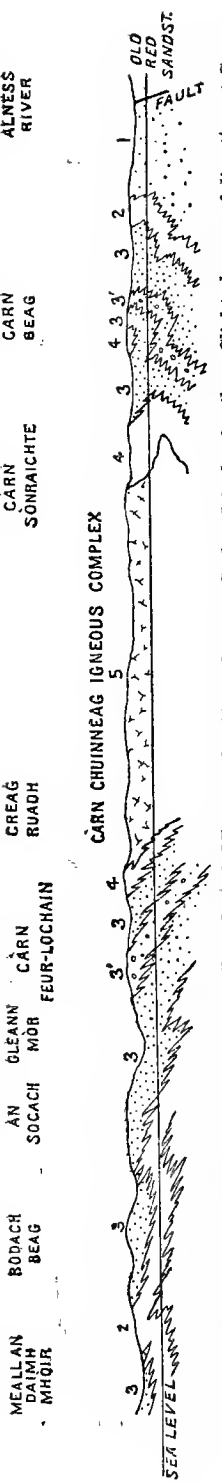


Fig. 1.—Diagrammatic Horizontal Section from Meall an Daimh Mhoir to the Alness River. Scale: 1 inch = 3 miles. Slight changes of direction at Creag Ruadh and Carn Sonraichte. 1, Lower Siliceous Group. 2, Lower Pelitic Group. 3, Upper Siliceous Group. 3', Pebbly portion of Upper Siliceous Group. 4, Upper Pelitic Group. 5, Intrusive rocks of the Carn Chuinneag Plutonic Complex.

It is, however, in the succeeding group (4) of mica schist and hornfels that the most complete evidence of the original sedimentary nature of the rocks is found. The sandy shales which chiefly compose it have been hornfelsed by the action of the granite, and have been thus so welded together that in the subsequent schist-making movements, many parts moved *en masse*, and escaped the sharp folding and molecular change which is indicated in the neighbouring rocks. The group forms a rim around the largest granitic mass, for most of its extent, and occupies a central position, in all probability part of a syncline, in the midst of the upper quartzose group (3), described above.

Within the aureole of the influence of the granite these rocks frequently have their bedding planes preserved uninjured, and even the original fine clastic grains are quite distinct. Suncracks and ripple-marks have also been observed on the surfaces of the bedding planes. The same beds are in the condition of hornfelsed shales, with no trace of foliation at one point, while, in other places, they are thoroughly foliated mica schists. An outlier of this group, in the form of mica schist, caps Carn Beag, east of Kildermorie.

To illustrate what is considered to be the most probable structure of the schistose area, the accompanying horizontal section, Fig. 1, has been drawn from near the north-west corner of the map in a nearly E.S.E. direction. The augen gneiss or foliated granite, believed to be a denuded laccolite, occupies the centre of the section, and is closely embraced by the rocks of the higher pelitic group (4), composed of mica schist and hornfels. The underlying siliceous schist (3), with its band of pebbly schist, occupies the surface on either side, and is succeeded by the lower pelitic gneiss (2), which forms the surface of a denuded anticline to the west of the augen gneiss. The lowest siliceous schist (1) never reaches the surface on this side of the latter gneiss. On the eastern side the pelitic gneiss (2) crops in one limb only of a major

fold, the eastern limb of which is nowhere seen in the map. This band of gneiss presents its whole thickness, and is followed on its eastern side by the underlying quartzose group (1).

It will be observed that in most parts of the section the folds are of an isoclinal type, their limbs dipping at various angles to the south-east. C. B. C.

We shall now proceed to describe more fully the development of the Moine Schists in different districts, taking first the areas on the south-west and south-east sides of the Older Granite.

SOUTH-WESTERN DISTRICT: GARVE AND LOCH LUICHART.

In the Loch Luichart region a distinct order of succession, shown below, can be made out in the rocks as they are followed outwards from the Lewisian inlier.

3. Upper siliceous zone; flaggy to massive quartz biotite granulites, with disseminated biotite in varying quantity; characterised by pebbly bands on certain horizons.
2. Pelitic zone; muscovite biotite schist and gneiss.
1. Lower siliceous zone; highly quartzose flaggy schists, with white mica.

A description of the structure on the eastern side of the inlier will be found in the Explanation accompanying Sheet 83. On the western side of the fold siliceous schists of zone 1 are seen on the south side of Loch Luichart with a south-easterly dip. The isoclinal folding appears to carry them beneath the Lewisian Gneiss, but in reality they are resting upon it. At the head of the loch the schists are truncated by the Strathconan N.N.E. fault (see Chapter IX.).

A similar succession obtains round the Lewisian Gneiss inliers north-east of Garve, which are surrounded by the flaggy, siliceous schists of zone 1. These are followed on the south-east by a belt of the pelitic gneiss of zone 2, and for some distance further to the east the rocks of these two zones alternate rapidly until they are succeeded by the broad belt of pelitic gneiss, of a peculiarly coarse and massive character, which extends south over Carn Gorm and Carn Fearna. On the eastern slopes of Carn Gorm the lower siliceous schists (1) reappear, and, interrupted only by a few small lenticular outliers of zone 2, occupy the whole area up to the margin of the Old Red Sandstone.

Passing to the north-western side of the Lewisian Gneiss, we find the lower siliceous schists (1) succeeded by a narrow band of pelitic rocks (2), the small breadth of the outcrop being chiefly due to its truncation on the west side by a fault nearly parallel to the strike. Further to the west a wide tract of country, extending to the line of the Strathconan N.N.E. fault, is occupied by the quartz biotite granulites of zone 3.

For a short distance from the last outcrop of the pelitic gneiss on the flanks of Little Wyvis, the south-easterly isoclinal dip is continuous, but between the Black Water valley and the fault the direction of inclination is variable, the irregularity, both of strike and dip, being particularly marked round the extremity of the augen gneiss.

That the great width of the area occupied by the rocks of a single zone is due to folding is well illustrated on the map, by the manner in which the successive folds of the underlying pelitic

gneiss plunge beneath the siliceous schists along the northern shore of Loch Luichart.

Within the area of this map the siliceous schists on the south side of Loch Luichart are different in character from those on the north side. The latter, with the possible exception of those about three-quarters of a mile south-east of Coille Coire Mhuilidh, belong to the upper siliceous zone (3). They must be separated from those on the south side, either by a folded crop of pelitic gneiss (2), which is hidden for the most part under the water of the loch, or by an east and west fault—possibly the continuation of the fault indicated three-quarters of a mile south-east of Coille Coire Mhuilidh.

On the west side of the Strathconan fault, and south of the Glascarnoch River, the ground in the south-west corner of the sheet is mostly occupied by the siliceous granulites of zone 3, through which the pelitic rocks of zone 2 appear at intervals in long lenticular masses along the crests of successive anticlinal folds. In this area the strike is somewhat abnormal, the direction of the axes of the steep-sided folds swinging round from N.N.E. and S.S.W. to N.N.W. and S.S.E.

The pebbly bands of zone 3, which have been described from the central part of this Sheet and from ground further west in Sheet 92, occur at several localities in this area. They are well seen in the sections laid bare by the Grudie River in the south-west corner of the map, and form a belt which extends northwards almost parallel with its western margin.

The Moine schists around the southern margin of the augen gneiss are much invaded by apophyses and veins of granitic material. On the west side of the Strathconan fault, near the head of Loch Luichart, there is an area in which the rocks are similarly invaded by foliated granitic material, leading to the inference that at this point the augen gneiss may possibly have been formerly present at no great distance above the surface now existing. The rocks on the east side of the same fault are not so impregnated in this locality. B. N. P.

BEN WYVIS DISTRICT.

The mountain mass of Wyvis, which may be considered to extend from the shores of Loch Glass to the foot of Little Wyvis, above Strathgarve, is mainly composed of the coarse garnetiferous muscovite biotite gneiss of the pelitic group 2, which occupies the centre of a compound reversed synclinal fold, whose axis runs N.N.E.-S.S.W., parallel to the trend of the ridge, and whose limbs dip to the south-east.

The overlying rocks of the upper siliceous zone (3) appear in numerous small synclinal folds upon the pelitic gneiss, the principal outcrops of the psammitic schists of the former zone being found south and south-west of Fiachlach, on the ridge at the head of Coire Mhoir, and on An Socach.

The complex nature of the folding is apparent in all the eastern corries of Ben Wyvis, and especially in Coire na Feola—the deep glen on the south side of An Socach—on whose precipitous rocky walls the rapid alternation of the pelitic and siliceous rocks along minor folds is finely displayed.

Passing to the eastern slopes of the mountain, we find the pelitic

gneiss immediately to the north of Loch Misirich, lying in a basin surrounded by siliceous granulites which dip beneath the gneiss. It thus seems probable that the psammitic rocks that form the northern slopes of the Allt nan Caorach valley, and extend over Meall na Speireig to Allt Gleann Sgathaich, belong to a lower series of altered arenaceous sediments—zone 1 of the Moine Series—which underlies the pelitic gneiss, and has been exposed by denudation along the east side of the Wyvis range. A study of the excellent section seen in the Allt Gleann Sgathaich, on the southern margin of the map, tends to confirm this interpretation of the structure. For more than a mile along the course of this stream the pelitic and siliceous rocks are rapidly interfolded at high angles, as shown on the map. The folds are seen in many places to pitch steeply in a S.S.W. direction, and it is evident that at these points the siliceous schists pass beneath the pelitic gneiss. L. W. H.

Where observed in Allt nan Caorach and along the parish boundary west of Meall na Speireig, the siliceous schists of this lower group weather unusually white, like quartzite, as is also the case with the schists of this group in other areas. Thin flaggy bands of flaky mica schist and others of "spangle-schist," with large mica flakes crossing the foliation, are also seen with associated pegmatites in Allt nan Caorach. C. B. C.

The rocks of the lower siliceous zone (1) appear again on the western side of the syncline, where they form a narrow belt along the lower slopes at the foot of Little Wyvis and Glas Leathad Mor, and extend northwards over the summit ridge of Wyvis through the depression, named on the six-inch map the Bealach Tom a' Choinnich, a mile south-east of Carn Gorm. The débris of these flaggy siliceous schists covers the *col*, and the rock is seen in place on the watershed at an elevation of 2859 ft.; sections are also exposed in the streams that flow down the slopes of Glas Leathad Mor and Little Wyvis. In the two northern tributaries of the Allt a' Gharbh Bhaid, bands of micaceous gneiss, that may be regarded as infolds from the overlying pelitic zone, appear amongst the siliceous flagstones. The same two streams each present a limited exposure of a highly felspathic, epidotic, acid gneiss, unlike the normal Moine gneisses, and resembling the more acid portions of the Lewisian Gneiss complex. It is quite possible that these may represent small infolds of the underlying Lewisian floor, similar to the larger inliers of undoubted Lewisian Gneiss further to the south, at Strathgarve.

Throughout the greater portion of its extent this lower siliceous belt is bounded on the west by the fault which runs in a north-east direction from the shore of Loch Luichart, nearly three miles east of its head, and almost parallel to the general strike of the rocks. On the ridge of Wyvis, where the siliceous schists (1) pitch beneath the pelitic gneiss (2), these two zones are thus brought into faulted conjunction with the higher zone (3) to the north-west. Further to the south the lower siliceous zone (1) is in contact with the rocks of the upper siliceous zone (3) for a distance of nearly four miles. The fault then forms the western boundary of the pelitic gneiss on the south-west flank of Little Wyvis, and the lower siliceous rocks, a little further east, occupy their normal position near the centre of the fold, with the pelitic gneiss on either side, and the Lewisian inliers

appearing along the core of the anticline. The siliceous schists (1) finally pitch out beneath the pelitic rocks in the vicinity of Strathgarve, close to the southern margin of the map. The course of the fault along the western slopes of Wyvis is for the most part concealed by superficial deposits, and its position is conjectural. The point where it crosses the Allt a' Bhealaich Mhoir, west of An Cabar, is, however, marked by crushing and brecciation of the siliceous schists.

The ground to the west, between the Loch Luichart fault and the Allt Coire Bheachain, is occupied by the upper siliceous zone (3) of the Moine Series, the most quartzose type alternating with rocks of more micaceous or semipelitic character.

The rocks over a great part of this area are arranged in apparently simple anticlinal and synclinal folds of considerable amplitude. The deep hollow which contains the waters of Loch Bealach Culaidh occupies the crest of one of these broad anticlines. On the summit of the ridge between that loch and the valley of the Allt Coire Bheachain, the schists are, however, thrown into a sharp anticlinal ridge, along the axis of which the beds are almost vertical.

The apparent simplicity of the structure over the central part of the area is, however, in all probability misleading, and there is more reason to assume the existence, in this region also, of a considerable amount of repetition due to minor isoclinal folds, although the presence of such folds cannot be so readily detected in these homogeneous rocks.

The pebbly bands referred to in the next paragraph as occurring on the east side of Loch Bealach Culaidh, and on the slopes of Carn Mor, occupy in both localities a position near the crest of one of the major anticlines, and are thus possibly on the same horizon. With regard to the structural relations of the biotite schists in the area west of Ben Wyvis to the upper siliceous group with which they occur, the fact that they enter into both anticlinal and synclinal folds of the latter group shows that they do not form part of the underlying pelitic series, but, as suggested later, are merely local intercalations in a generally siliceous series.

Quartzose Schists.

The siliceous schists in the region between the Ben Wyvis escarpment and the valley of Loch Bealach Culaidh are usually thick-bedded and of somewhat massive habit. Felspar in a thoroughly granulitised condition is present in varying amount, and is most abundant in the massive granulites of Carn Gorm, where it is of a pinkish colour. The rock also contains a variable quantity of irregularly disseminated biotite. Coarser bands, containing recognisable clastic grains and more or less distinct pebbles, mostly of felspar, occur at the junction of the Allt a' Gharbh Bhaid with its highest tributary on the east bank, on the south-east shore of Loch Bealach Culaidh, and on the southern slopes of Carn Mor. Intercalated with the siliceous granulites in many places are thin bands or seams of fine-grained mica schist. These micaceous rocks reach a greater development in the valley of Abhuinn Beinn nan Eun, where a belt of dark biotite schist and biotite muscovite schist, a few hundred yards in breadth, crosses the glen three-quarters of a mile above the head

of Loch Glass. The rock is a very fine-grained schist, often with a silky lustre, in which biotite is the predominant mineral. The minute puckering due to incipient *ausweichungsclivage* is a common feature of these schists, and a distinct cleavage-foliation, oblique to the bedding planes, can often be detected. It is to be observed that where the mica schist is intercalated with thin bands of quartz schist, the cleavage planes do not cut the harder siliceous material.

With the biotite schist at this locality is associated a thin band of garnetiferous hornblende zoisite granulite, which presents the spotty character and nodular weathering that prevail in these zoisite-bearing rocks. A specimen from this band, examined under the microscope by Dr. Flett, is described by him as follows (11129):* "In a granulitic quartzofelspathic groundmass lie scales of biotite, small rude prisms of pale greyish-green hornblende, idiomorphic pale pink garnets studded with grains of quartz, and colourless zoisite in small prisms half a millimetre in length and one-tenth of a millimetre in breadth. These zoisites give grey or blue interference tints, but some are nearly isotropic. There is a little granular sphene, and small crystals of iron oxide, but the rock contains no muscovite."

Similar bands of dark lustrous biotite schist, often with small garnets, occur on the north-east side of the Queen's Cairn, and above Loch nan Druidean. It should be mentioned that, from their structural relations to the quartzose schists with which they occur, these micaceous bands are regarded as original argillaceous intercalations in the siliceous group, and not as forming part of the underlying pelitic group, to be presently described.

Semipelitic Group.

A semipelitic class of schists, formed by the metamorphism of sediments of intermediate character, or rapidly alternating between the purely argillaceous and arenaceous types, is found on the east side of Allt Coire Bheachain, and extends southwards to the margin of the granite on Carn Mor. They may be described as fine-grained, thoroughly granulitic quartz biotite granulites, in which the ferromagnesian mineral is disseminated through the rock in small flakes, and is not markedly orientated. There are also bands of highly siliceous rock in which the mica is almost entirely absent. The original bedding planes are indicated by numerous dark laminæ rich in black mica, representing muddy films in a more sandy deposit. The irregular arrangement of these planes suggests in many places the effects of false- or current-bedding.

Pelitic Gneiss.

No particular features have been observed in the gneisses of Ben Wyvis distinguishing them from rocks of the same group in other parts of the region.

The rock presents the usual character of a generally coarse, muscovite biotite gneiss with wavy or corrugated folia, and often highly garnetiferous, the garnets occurring either as idiomorphic crystals or in aggregates.

A finer-grained and more evenly foliated flaggy type is also met

* The number of the micro-section in the Geological Survey Collection.

with. These flaggy gneisses alternate more or less with the coarse-grained massive rock throughout the area, but tend to become the predominant type at the eastern edge of the main outcrop, that is to say, in the lower portion of the group.

Tourmaline Pegmatites.

On the eastern slopes of Ben Wyvis, rather less than a mile W.N.W. of Loch Misirich, there occur, both in the pelitic and siliceous schists, two or three thin veins of coarse muscovite pegmatite containing garnets and idiomorphic crystals of tourmaline, the latter sometimes reaching a large size. Fragments of silvery muscovite schist with abundant tourmaline also occur amongst the hill-wash and thin drift that covers the hillsides above Loch Misirich, but the rock from which they are derived has not been met with in place. L. W. H.

DISTRICT OF STRATH RANNOCH.

This district includes the eastern side of the strath near the keeper's house in Strath Rannoch, and extends eastwards to Loch Coire Bheachain and Allt Coire Bheachain. From the foot of this burn the boundary proceeds along Abhuinn Beinn nan Eun to the granite.

Most of the Moine schist in the area is siliceous in character. A band of more pelitic rock occurs along the granite margin to the north-east of Carn Loch nan Amhaichean, and, after running south-east for a short distance, is shifted north-eastwards along with the granite margin for a distance of nearly a mile, by a north-easterly fault, in all probability a continuation of the Strathconan fault which runs past the head of Loch Luichart (see Chapter IX.).

This band has been indicated on the map, but there are numerous minor occurrences of pelitic material among the siliceous schists to the south which have not been picked out. The greater portion of all this pelitic material is in the form of hornfels. On the west side of Loch Coire Bheachain a considerable crop of semipelitic schist, without any indications of hornfelsing, intervenes between the north-eastern end of the Inchbae granite and the siliceous schist, but it appears to be cut out in a westerly direction by a transgression of the granite across the bedding.

The siliceous schist to the east of Lochan Gobhlach is often gritty, and sometimes contains little pebbles of quartz and felspar. The schists for some distance south of this loch also show distinct remains of pebbles and unmistakeable false-bedding. In one spot, about 100 yds. south of the southern end of the loch, scattered blocks, partly of siliceous and partly of semipelitic character, which are evidently nearly *in situ*, show various types of pebbles of unusually large size. Among these pebbles are some of siliceous granulite, approaching granulitic quartzite in character, and a good number which show small porphyritic crystals of quartz embedded in a pink granulitic matrix, and have probably been derived from quartz felsite.

Many of the felspar pebbles show no appreciable deformation (Fig. 2), and are remarkably free from granulitisation. Those that have been examined under the microscope by Dr. Flett consist

of microcline or microcline-perthite. One of the pebbles consists of graphic granite (10905) with coarsely hatched microcline. In

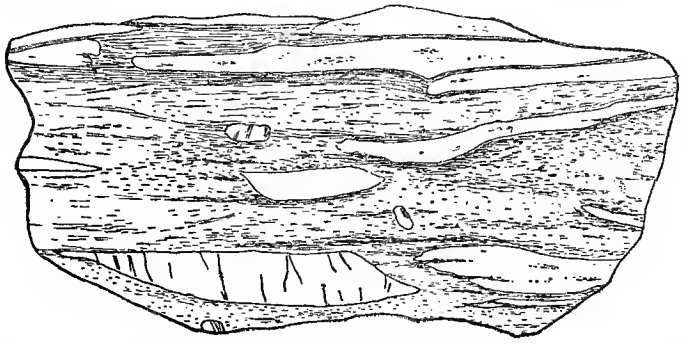


FIG. 2 (×1).—Piece of Pebbly Schist nearly *in situ* 100 yds. S.S.E. of south end of Lochan Gobhlach. The most elongated pebbles probably represent quartz felsites and quartzites. The large one near the bottom is quartz. Two small ones near the middle, and a third small one at the bottom are felspar.

great contrast to the felspar pebbles, those of quartz are always greatly deformed,* and some of them form flattened, occasionally bent ribbons, which are six or seven inches long, though hardly an inch broad and only half an inch thick.

Even longer than the quartz pebbles are some which probably represent quartz felsite. It was, indeed, this great elongation compared to the stumpy form of the undoubted felspar pebbles which led to the first recognition of their composite character.

Irregular patches of greenish-grey micaceous schist occur in close association with undoubted pebbles, but it is possible that they represent contemporaneous "galls" formed of soft unconsolidated material.

In a pebbly schist 190 yds. slightly south of east of the south end of the loch, small grains of epidote and small octahedra of magnetite are very abundant in certain laminæ, arranged in a way which is strongly suggestive of false-bedding. Epidote occurs in thin veins crossing the bedding, and also as grains replacing felspar in some of the pebbles; but it is believed, owing to the mode of distribution described, that in the main both epidote and magnetite represent original heavy sediments.

These interesting pebbly beds are probably only half a mile from the granite, but they show no clear hornfelsing. The foliation planes are lustrous with abundant scales of white mica, large enough to be separately discerned with a hand lens, and the matrix is thoroughly granulitic and can often be seen to sweep round the pebbles.

The beds close to the granite on Meall nan Sac are also usually epidotic, and some bands, which are not quite so lustrous as the rest, contain pebbles an inch and a half long. These pebbles are, however, to a large extent granulitic, and it is not clear that they represent any

* A similar contrast has often been noticed before. See, for instance, 'The Geological Structure of the North-West Highlands of Scotland,' *Mem. Geol. Survey*, 1907, p. 620.

substances except quartz and felspar. They are often elongated along a foliation which crosses the bedding almost at right angles.

C. T. C., E. M. A.

DISTRICT OF LOCH GLASS, LOCH MORIE AND STRATH RUSDALE.

Roughly speaking, four great bands with a north-east and south-west strike cross this district. They are as follows:—*

4. A band of mica schist and hornfels, with a breadth varying from half a mile to one mile, which follows the margin of the augen gneiss from Beinn nan Eun northwards.
3. A quartzose series with subsidiary bands of mica schist, and with an average breadth of three miles.
2. To the east of the above quartzose series a band of garnetiferous mica schist, with a breadth varying between half and three-quarters of a mile. This extends from Loch Glass to the margin of the Fearn granite, which truncates the crop.
1. Another quartzose series differing somewhat in lithological character from (3), and extending from Loch Glass to Beinn Tharsuinn and Torr Leathann. This lies on the eastern side of the garnetiferous mica schist (2), and is bounded on the east by the Old Red Sandstone.

In describing these four bands, we will begin with that last mentioned (1), which is believed to be the oldest.

1. *The Lower Quartzose Group.*

The rocks of this group are well displayed on the eastern flank of Beinn Tharsuinn, on the tops of Torr Leathann, Cnoc an t- Sithein Mor, Cnoc an t- Sithein Beag, and in crags facing the lower part of Strath Rusdale at Balnacraig. A good section can also be seen in the Tollie Burn, from its source in Beinn Tharsuinn to about a third of a mile above Braetollie, where the Old Red Sandstone is faulted against the schist. South of Strath Rusdale it is again exposed on Cnoc na Sroine, and also in the bed of the Alness River, above its junction with the Black Water. Other exposures are seen in the crags near Boathvic, on either side of the lower part of Loch Morie, along the northern shore of Loch Glass, and in Glen Glass above the fault at Eileanach. These quartzose rocks everywhere dip to the south-east, but they are isoclinally folded, and it is probable, from the constant repetition of bands of a similar nature, that no great thickness of strata is represented. All the types are thoroughly granulitic. The most characteristic are massive and flaggy rocks, very quartzose and weathering white like quartzite. They are of a pale brownish colour when broken, but contain very little mica. Others are pink and grey, coarse-grained and with some resemblance to granite, owing to the large proportion of felspathic material. With these are flaggy, very siliceous "spangle-schists" with large, brilliant, rounded flakes of mica, resembling fish scales, scattered over the division planes: the flakes lie at various angles to these planes, and are evidently of secondary origin. These rocks are associated with schists of a "papery" character, consisting chiefly of large flakes of mica and

* The numbers in the list attached are the same as those already used in this chapter for the corresponding bands in other districts.

strings of pegmatite. The " papery " schists evidently form passage-rocks into the overlying garnetiferous mica schist, which occurs as bands and infolds, increasing in number and size as they approach the great band to the westward. These bands are usually flaggy, but sometimes more or less massive, and often contain well developed garnets. Dark, fine-grained mica schists are conspicuously absent. The bands of garnetiferous mica schist are evidently mostly due to folds which have brought down into the quartzose series portions of the formerly overlying garnetiferous mica schist, now removed by denudation. An anticlinal arrangement of the quartzose bands was detected on the shore of Loch Glass, opposite Culzie Lodge, but no other structural evidence for the relation of the two series was observed. Better evidence has, however, been obtained in areas to the south mapped by Messrs. Hinxman and Peach, as already described (pp. 15, 17). It is noteworthy that no intrusive sills of epidiorite, such as occur in association with this group and the overlying mica schist, have been detected in the other groups of this area.

2. *The Garnetiferous Mica Schist.*

This schist can be traced as a continuous band over half a mile in width from Sithean a' Choin Bhain, on Beinn Tharsuinn, across Cnoc a' Mhadaidh into Strath Rusdale between Dalreoich and Balnacraig, whence it crosses the low ground south of Am Mam into the valley of the Alness River below Loch Morie. Here it comes against the Loch Morie fault, which on its south side shifts all the metamorphic rocks and the Old Red Sandstone to the westward, as will be further described in Chapter IX. The mica schist is again seen in the crags on the south side about half-way up Loch Morie, whence it passes over Meall Beag to the north shore of Loch Glass. The best exposures of this band are seen at Cnoc a' Mhadaidh, north of Strath Rusdale, and in the crags beside Loch Morie and Loch Glass. In these places the rock is a massive dark bluish grey mica schist, and breaks up into immense blocks which lie piled in confusion at the base of the crags. It consists chiefly of muscovite and biotite, in small and large scales, with lenticles and strings of pegmatitic material. Garnets are very numerous, and in the most massive types are usually in the form of crushed aggregates, but idiomorphic garnets, with well-developed crystal faces and of a beautiful pink colour, are not uncommon, and are found by themselves in the more flaggy types. About a mile north-east of the cairn on Meall Mor, a thin calcareous band, weathering with a porous surface, was observed near the south-east margin. It is rich in calcite, and contains also zoisite, hornblende, and large garnets (11027). It must have been an arenaceous limestone originally. The pegmatitic material often occurs in the form of augen wrapped round by the other constituents of the rock, and great lenticular masses of coarse pegmatite are also found, which are difficult to distinguish from dyke-like masses of similar material which occur along the strike of the rocks. These dyke-like pegmatites are mostly associated with the more flaggy types of mica schist to the east of the main band. They consist of clear quartz and white felspar with plates of white mica, which are frequently several square inches in extent, and an inch or more in thickness. Garnets are not uncommon in the quartzo felspathic

material, and also lie embedded in the plates of white mica. They then split with a perfectly smooth surface along the same planes as the cleavage of the mica. Where the band of garnetiferous mica schist crosses from Loch Morie to Loch Glass it dips south-east at angles of 30°–45°, but the true dip is often difficult to make out, owing to the massive character of the rock and the absence of distinctive bands. North of Strath Rusdale the dip is in the same direction, but at higher angles. Along its eastern margin the band is followed by constant repetitions of the flaggy spangle-schist, and bands of more massive mica schist with intercalations of the quartzose group already described. The alternation must be largely due to folding together of the two groups. The western margin, on the contrary, is generally very abrupt, a fairly massive mica schist giving place to a flaggy siliceous schist, with scarcely any repetition of mica schist. To the west of Beinn Tharsuinn, however, a few folds of the same type of mica schist occur to the west of the main band.

3. *The Upper Quartzose Group.*

The rocks of this group appear to dip beneath the garnetiferous mica schist on Cnoc a' Mhadaidh, Meall Beag and the crags beside Loch Glass. This is due to the fact that they are folded into isoclines dipping east, so that the mica schist, which we suppose to be really older than the quartzose rocks on its west side, appears to overlie them. Along this boundary the rocks are rather flaggy, with finely divided glistening micas on the division planes, but further west they pass rapidly into a more massive type, pink and grey in colour and rather felspathic, in which original clastic grains of quartz and felspar can often be distinguished. The amount of mica is usually small in these massive rocks, but lines of heavy dark minerals are common, and often give an appearance of false-bedding. The bedding planes are usually distinct, and a foliation may often be detected crossing them. Thin layers of fine silvery mica are frequently found on the bedding planes; numerous smooth joint faces are also conspicuous. Except with the most massive types, bands of fine-grained dark mica schist are found, which have a very different appearance to the garnetiferous mica schists. Though all the constituents are small, these dark schists evidently contain more biotite than white mica. When they occur in large bands they have frequently a crimped or crinkled structure, which seems connected with an incipient strain-slip cleavage. Garnets of small size are occasionally seen. This wide belt of rock shows constant reversals of dip, and is probably much folded. The best exposures are in the following places: the bed of the Black Water in Strath Rusdale; Leathad Riabhach and Carn Beag, both to the north of Loch Morie; Creag a' Ghaoirr and the crags north of Wyvis Lodge. Along the western margin of the band a rather different type of rock is met with, which may in part owe its present appearance to the thermal influence of the granite mass. This type is flaggy and contains thin bands of white quartzite which break up into slabs, on the surfaces of which ripple-like markings have been detected in the Coire nan Sgulan, south of Loch a' Chaoruinn. Original clastic grains are frequent, and pebbles have been noticed in some bands. These quartzite bands were traced from Coire nan

Sgulan southward to Beinn nan Eun. A band of dark crinkled mica schist occurs on the top of Carn Beag, north of Loch Morie, and a band of similar nature was mapped south of Creachan nan Sgadan. In both these places there is reason for thinking, from the direction of the dips, that the mica schist is lying as an outlier on the more siliceous rocks. This is an important point in relation to the mica schist and hornfels band next to be described, as the rocks of Meall Toll a' Choin and An Claigionn, in the neighbourhood of Kildermorie, which form the outer part of the band, are identical in character with the mica schist of the outliers on Carn Beag. It affords evidence that the mica schist and hornfels series overlies the quartzose group now described, and is therefore the highest sedimentary series in the metamorphic rocks of the district.

4. *Band of Pelitic Mica Schist and Hornfels.*

In this band we have rocks of very different type associated together, owing to some parts of the original argillaceous sediment having been hornfelsed by the intrusion of the granite. There is evidence that the hornfelsing took place previous to the great series of movements which have so powerfully affected the granite and sediments, turning them into schists and gneisses. The band is in contact with the granite from Meall na h-Uigeig to Beinn nan Eun. It is about half a mile in width at the former place, but gradually widens to about a mile near Kildermorie. On the south side of the Loch Morie fault it extends from Meall a' Chaoruinn to Beinn nan Eun, but siliceous rocks come into contact with the granite on the western slopes of the latter mountain, and the western boundary of the argillaceous band leaves the granite margin, proceeds in a south-easterly direction, and joins the eastern boundary before it reaches the Abhuinn Beinn nan Eun, the band thus coming abruptly to an end. From Kildermorie, northward, it has been found possible to separate this band into an inner zone bounding the granite, which is chiefly composed of hornfels, and an outer zone in which the rocks consist of mica schist. The hornfels, and the shearing movements which have in places affected it, will be subsequently described in Chapter V. The outer zone has been more or less completely turned into mica schist. On An Claigionn, where these mica schists have a breadth of considerably over a quarter of a mile, the bedding has been almost obliterated, and the rocks are identical in character with the mica schist which has been described as capping Carn Beag, more than two miles distant from the granite margin. Much white segregated quartz is associated with this crinkled mica schist. Between Bad a' Bhathaich and Carn Cas nan Gabhar the rocks are in the form of silky phyllites in which the bedding is still quite distinct, though crossed at a high angle by the foliation. We can walk along the strike of the bedding from these mica schists and phyllites on to the hornfels, and it is clear that these three types of rock represent one band of sediment which has undergone diverse modes of metamorphism It is probable that much of this outer zone was never affected by the thermal metamorphism which produced the hornfels, but that many of the beds in it were metamorphosed directly from their original shaly condition into mica schists. Those beds which have now the character of phyllites

were, however, probably more or less hornfelsed previous to the advent of the mechanical metamorphism, and so resisted the thorough change shown by the adjoining mica schist.

South of the Loch Morie fault it was not found possible to separate zones corresponding to those just described. The hornfelsing action of the granite has in many places extended to the outer margin of the argillaceous band, and even affected the siliceous bands in the neighbourhood, which have in consequence retained more of their original structures than is usual. C. B. C.

DISTRICT SOUTH-WEST OF KINCARDINE.

The boundary of this district is taken through Creag na Ceapaich and Carn an Liath-bhaid, and along the margin of the granite to the burn south of Meall na h-Uigeig. It follows this burn down to Garbhairidh, and then crosses over Cnoc Leathad na Siorramachd to the Old Red Sandstone on Struie Hill.

The district includes a great part of the Newer Granite of Corriefearn, the main mass of which extends in a N.N.W. direction for about six miles, and is often nearly three miles broad; the description of this rock is reserved for Chapter VII.

Most of the area is composed of siliceous schist, but the pelitic or semipelitic beds are also well represented by a broad band keeping along the margin of the Older Granite, and by two others which are cut off almost at right angles by the eastern margin of the Newer Granite.

The band along the margin of the Older Granite varies in breadth from a mile to a quarter of a mile, and curves, with the granite margin, from a west-and-east direction at the north end, to a north-and-south direction, and then to S.S.W. The portion next the granite, and another portion half a mile N.N.E. of Carn an Liath-bhaid, are differentiated on the map from the rest, as they have to a large extent escaped shearing, and still show hornfelsed characters, as described in more detail in Chapter V.

In the Abhuinn a' Choire Bhuig an exposure of lustrous pelitic mica schist, about 200 yds. broad, lies a little east of the pelitic band which adjoins the granite, but probably merely represents a folded portion of it.

The two pelitic bands east of the Newer Granite make a close approach to one another just as they reach it, and there can be no doubt that they are both folded portions of the pelitic series which is so well seen south-west of the Newer Granite. For various reasons, already given near the beginning of this chapter, this series is considered to be lower in original stratigraphical sequence than the pelitic series which margins the older granite.

The bedding of the schists is usually steep, often vertical, and isoclinally folded. Near the Older Granite the strike is nearly the same as its margin, but further away this is not always the case, the general strike both in Allt Eiteachan and the burns east and south-east of Creag na Ceapaich being somewhat north of east, nearly at right angles to the adjacent margin of the granite, but approximately parallel to the long axis of its outcrop. On the east side of the Newer Granite the general dip is south-east and steep.

The pelitic bands consist in the main of lustrous mica schist, often

garnetiferous, but semipelitic and siliceous intercalations are well represented. Thin seams containing hornblende and garnet are also found both in the schists margining the Older Granite, and in that band which crosses over Cnoc an Liath-bhaid, east of Corriefearn; in the former band they may be seen on the south side of the burn 1100 yds. slightly east of south of Creag na Ceapaich, and in the latter very near the hill-top. These seams are similar to others which are seen still better in other districts, particularly the two (Strath Vaich and Gleann Beag, etc.) to be next described.

Perhaps the best exposures of the siliceous schists are in the following localities: the coast near Kincardine; the two burns south and south-east of Creag na Ceapaich; the hillsides a mile east and south-east of Meall na h-Uigeig. Many bands are so massive and siliceous that they might be called granulitic quartzite, but these are mixed with numerous more micaceous pelitic schists, much too thin to be shown on the map. Small clastic quartz grains are tolerably abundant, but perhaps never so large as peas, and false-bedding is frequently discernible. The bedding is repeatedly folded in the burn half a mile south-east of Creag na Ceapaich, and on the hillsides near Meall na h-Uigeig, but it is to be noted that while in the former locality the axial planes of the folds strike E.N.E. and usually incline S.S.E. at low angles, in the latter they are nearly north and south. In the burn a quarter of a mile south-east of Creag na Ceapaich the stretching is N.N.W.-S.S.E., nearly parallel to the dip of the foliation.

The siliceous schists between the two broad pelitic bands east of Corriefearn are best seen on the coast.

W. G., C. T. C., L. W. H., E. M. A.

STRATH VAICH DISTRICT.

The northern margin of the district is taken along Gleann Beag and Gleann Mor to the foot of Alladale River. The eastern boundary extends from the last-mentioned locality over Dunan Liath and Beinn Tharsuinn, and thence southward along the western margins of the granite masses as far as Strath Vaich.

Three chief zones of rock traverse this district. One of these is a garnetiferous pelitic mica schist, which has been traced into the garnetiferous mica schist band already described on the east side of the foliated granite. Siliceous schists are found on both sides of this mica schist, but are considered to belong to one group, which probably occupies a higher stratigraphical position than the mica schist.

In the western part of the district the general dip, which perhaps merely indicates the dip of limbs of isoclinal folds, is eastwards, but it is decidedly less at the extreme western edge than a mile or two further east: thus, on the west side of Meallan Ban it is 30° or 40°, but a mile to the east of this hill it is 60° or 70°. Near Lubachlaggan, at the head of Strath Vaich, the beds are vertical or dip steeply west or south-west, and are often twisted along nearly horizontal axial planes, so that the portions above certain planes may dip very differently from those below.

In the north-eastern part of the district the dip changes from east to south and then to south-west, as we advance north-easterly.

Two bands of garnetiferous mica schist have been traced from the

western slopes of Meall an Torcain, near Glascarnoch, almost continuously in a N.N.W. direction across Tom Ban Beag and Tom Ban Mor to Creag Rainich and Meall Gorm. These bands have a breadth of outcrop of 50 to 100 yds. From Meall Gorm across Meallan Ban to Glenbeg, only one band, increasing in breadth northwards, has been mapped. At Glenbeg it has a breadth of over a mile, extending into the adjoining one-inch map 92, and contains minor folds or bands of siliceous rock. At Meall an Torcain the dip is about 60°, and E.N.E. Near Glenbeg it is often only 30° to the south-east, this latter small angle possibly accounting in part for the greater breadth of outcrop in the north-west corner of the map. Good sections of these schists are seen on the western flank of Meall an Torcain, at Creag Rainich and on Meallan Ban. Specimens from different localities show much the same characters. They consist chiefly of large scales of muscovite and biotite with thin strings of pegmatitic or quartzofelspathic material and numerous garnets. On the whole the rock is not so massive as the mica schist of Loch Glass and Loch Morie, and the garnets are more usually idiomorphic than in that rock.

Thin siliceous seams, rarely more than a few inches thick and interbanded with still thinner seams of a dark grey colour, are not uncommon in the garnetiferous mica schist in the burn about three-quarters of a mile N.N.E. of Meallan Ban, and they occur also in the crags a mile north-west of Clach Sgoilte. These siliceous seams usually contain garnet and hornblende in fairly conspicuous prisms, and the dark grey seams are generally rich in zoisite, so that it seems probable that they both represent layers which were originally calcareous. Similar seams are also found in other districts in this one-inch map, and also in one-inch map 92, where they were first described by Messrs. Gunn and Teall.*

Several large dyke-like pegmatites accompany the mica schists on Tom Ban Mor and Creag Rainich. They are white, coarse, often show a graphic structure on a large scale, and contain garnets and large crystals of muscovite. The rock closely resembles the pegmatite formerly quarried on the northern shore of Loch Garve. This Garve pegmatite was a transported boulder, and may have been carried by ice from one of the exposures referred to.

Among the siliceous schists in the area between the Glascarnoch River and Abhuinn a' Ghlinne Bhig, that is, in the Strath Vaich and Tollomuick Forests, and also in the ground between Deanich and the granite margin about Beinn Tharsuinn and Crom Loch, certain groups of rocks of distinctive character, which extend for great distances along the strike, can be made out. Massive quartzose schists with some of more flaggy character are found in the ground between the garnetiferous mica schist and Strath Vaich. These rocks are thoroughly granulitic and quartzofelspathic, with varying though usually small proportions of micas. Bands of dark mica schist, which sometimes show the peculiar crinkled structure due to strain-slipping, are found on Meall an Torcain, Meall Coire nan Laogh, Carn Gorm-loch and Clach Sgoilte. Dark mica schists of the same kind are also found to the east of these localities, but are scarcer and not so thick, and at the same time the associated schists become coarser in grain, more quartzofelspathic, and less micaceous. With these dark mica schists occur

* *Summary of Progress of the Geological Survey* for 1897, p. 41.

others of similar type to the garnetiferous mica schist, but these latter are not so numerous and do not extend far from the main garnetiferous band.

The siliceous schists west of the garnetiferous mica schist do not differ appreciably from those on the east. They are best seen in the following localities: the western slopes of Tom Ban Beag, Allt Airidh Cheiridh, a mile and a half slightly west of north of Strathderie and the western crags of Meallan Ban. In the two last localities they are generally massive and often show indications of false-bedding, but no distinct clastic grains were detected. On the supposition that the outcrop of the garnetiferous mica schist is here the denuded upper surface of a compound anticlinal fold appearing from beneath the accompanying quartzose rocks, a repetition of rocks of the same character, like this, would be expected.

In Strath Vaich, between the Lodge and Loch Toll a' Mhuic, and thence along the low hollow to Deanich, and, following the change in the strike of the rocks on the southern slopes of Gleann Mor, we find a more flaggy type of siliceous schist with the bedding planes covered with silvery films of white mica. The occasional more massive rocks in association with these are very quartzose, fine-grained, often of a peculiar bluish colour, and contain similar films of white mica on the bedding planes. Original clastic grains are not unfrequent in these flaggy rocks, especially along Gleann Mor, but it is in the rocks next to be described that the most striking evidence of such grains has been obtained.* These rocks form the mass of Beinn a' Chaisteil, and have been traced across Crom Loch and Carn Feur-lochain to Dunan Liath, and for a considerable distance further to the eastward. They form a band considerably over a mile in width in the neighbourhood of Beinn a' Chaisteil and Crom Loch. They are coarse-grained, pinkish and grey, quartzofelspathic schists, poor in mica. The bedding is well preserved, and curved lines of darker minerals, suggesting false-bedding, are very noticeable. Numerous smooth slickensided joints are also common. Original clastic grains are abundant, and every here and there bands containing rounded pebbles, generally of quartz or felspar, but more rarely of a composite nature, are seen (slides 10438–10444). Slide 10438 contains fragments of micropegmatite as well as grains of magnetite, while others contain pebbles of quartzose sediment. The quartz pebbles are usually of a pale lilac colour, and some have been found over an inch in diameter. Quantities of these pebbles weathered out of the rock are strewn over the flat top of Beinn a' Chaisteil, and form in places a thin gravelly layer. Where least affected by shearing movement the rock has the appearance of a coarse grit or fine conglomerate, though on close examination the matrix is always found to be granulitic. The pebbles show every degree of breaking down. Some are partly granulitised and traversed by cracks. Some have their ends drawn out into long tails of granulitic material, and others are thoroughly granulitic and have shadowy outlines. Although some of the quartz pebbles have been intensely flattened and rolled out to perhaps more than twice their length, others have retained their rounded outlines in a remarkable manner. The felspathic and other pebbles are rarely of such large dimensions as the quartzose ones described above. Lenticular masses of pelitic

* *Summary of Progress of the Geological Survey* for 1902, p. 85.

schist are not uncommon in these rocks, and probably represent original "galls" which have been drawn out and twisted. The bands containing the largest pebbles seem to be most numerous along the strike from Feur-lochain to the summit of Beinn a' Chaisteil. It is remarkable that the only band of pelitic character found in association with these pebbly rocks shows a much lower degree of metamorphism than the micaceous bands in the other groups described. This band is only a few feet wide, and occurs near the outer margin of the pebbly rocks seen in the burns on the western flank of Beinn a' Chaisteil. The rock is a pale grey silvery phyllite, with the original bedding still indicated by distinct bands of different colours, which are crossed by the foliation at a considerable angle. In degree of metamorphism, it resembles the phyllites of Bad a' Bhathaich, which are associated with the hornfels on the eastern side of the granite, as described in Chapter V.

On approaching the granite the siliceous schists lose their pebbly character, no pebbles being noticeable on Creag Dhubh Bheag and Beinn Tharsuinn. They keep their massive character for some distance, but then become flaggy and mixed with thin lenticular seams of hornfelsed pelitic material. It is evident that these lenticular seams are forerunners of the thick band of hornfels which is found along the margin of the granite a little further east. C. B. C.

The southerly continuations of some of the Beinn a' Chaisteil beds are seen in crags nearly three-quarters of a mile north of Meall a' Ghrianain, and also in the burn which runs eastward from these crags. In both these localities clastic grains of quartz and felspar are fairly distinct, but are rarely more than half an inch long. Some of the grains have been pulled out into long granulitic streaks and now strike about 45° south of the direction of dip of the beds—which is generally west, at high angles.

The siliceous schists east of the broad garnetiferous mica schist sometimes contain lenticles, from several inches to several feet in length, which are very white at the outsides, owing to the scarcity of biotite in these positions, though flakes of biotite of unusually large size are not uncommon near the centres. Such lenticles are well seen near the junction of the burns half a mile south-west of Glenbeg house, and in various parts of the burn three-quarters of a mile east of Meallan Ban. The margins of the lenticles are not very definite, but they often cross both the regular bedding and the minor false-bedded laminæ. In the slice of a specimen (10369) from the locality near Glenbeg, epidote is very common in small irregular crystals, and is associated with some zoisite; a few grains of sphene and garnet are also present. The four minerals just mentioned are all lime-bearing, and it appears possible that the lenticles represent old calcareous nodules (analogous to the calcareous "lunkers" found in some Carboniferous sandstones), which were in existence prior to the metamorphism of the rock. The best exposures, however, show no clear evidence of deformation.

Thin pegmatitic streaks, about an inch thick, and with ungranulatised felspar, are not uncommon in the siliceous schists near Strathderic, and some of them have been observed to cut quartz veins.

In various parts of the burn three-quarters of a mile east of Meallan Ban, the siliceous schists, which are usually so hard, have weathered into such a soft state that you can scoop them out of the burn-side

with the finger, and they have at the same time acquired an unusual yellowish brown colour. The reason of this peculiar change is not known.*

Along a great part of the western margin of the district strong joints incline west at 30° or 40°, almost directly opposite to the dip of the foliation. C. T. C.

GLEANN BEAG, GLEANN MOR, COIRE MOR AND ALLADALE.

This district includes all the area north of Gleann Beag and Glean Mor as far down as the foot of Alladale River.

Much the larger part consists of siliceous schists, but the western extremity is crossed by a broad band of pelitic schist which enters from the south and at first strikes north, but gradually assumes a north-east direction. In the area north-west of Glenbeg house, where the evidences of folding are unusually abundant, and the fall of the ground nearly agrees in direction with that of the comparatively gentle general dip of 20° or 30°, the breadth of the band is in places more than two miles, the western portion being in one-inch map 92.

The pelitic band, rather less than a quarter of a mile broad, which strikes S.S.E. at the east end of the district, has been traced further northward in one-inch map 102, and is found to broaden out and join up with the western band just described.

In most of the district the dip of foliation, or of limbs of isoclinal folds, is E.S.E., and increases in amount as we proceed in the direction of dip. Thus, near Coire Mor it is only 20° or 30°, but at Deanich Lodge often 60°. Near the eastern end the dip changes through south-east to south, and, finally, near the foot of Alladale River, to south-west and W.S.W., at a steep angle, sometimes 70° or 80°.

Many of the crags on the north side of Gleann Beag, a little below Glenbeg house, show a second foliation parallel to the axial planes of fold and crossing the bedding, which is in places nearly horizontal. Isoclinal folds, with axial planes inclining east or E.S.E., are repeatedly seen in the pelitic schists north-west of Glenbeg house, and in the area between Coire Mor and Toll Lochan; the pitch is southerly in all these places, and usually about 20°. Folding has not been so often observed in the siliceous schists as in the pelitic, presumably because the former, being in thicker beds than the latter, have moved *en masse* more frequently. They are, however, repeatedly folded in the crags two-thirds of a mile east of Coire Mor, and in a still larger and clearer manner about half a mile west of Bodach Beag.

A large fault strikes north-west down Coire Mor, and displaces the north-west margin of the pelitic band for about 800 yds., the north-eastern portion of this margin towards the north-west. The apparent displacement of the south-eastern margin is less—about 500 yds. The direction of displacement is the same as would be expected from a normal fault with a south-west inclination, and such an inclination is seen in several places in the stream near the head of the glen.

The siliceous schists on the north-west side of the broad pelitic band in Coire Mor seem somewhat more massive and less mixed with minor pelitic bands than those on the south-east side. It was,

* The change is referred to again in Chapter X. Siliceous schists in a similar soft condition are also mentioned in the next district described.

therefore, the first impression, that the beds on either side were not likely to represent one horizon on opposite sides of a fold. But, if the fold is of great height or depth, the original distance between the two sides now exposed may have been sufficiently great to allow of considerable change of sediment.

One of the commonest types of siliceous schist is sub-flaggy, being divided into beds six or eight inches thick, which are separated by somewhat more micaceous layers, often about a quarter of an inch thick. This type is well seen in the crags on the north side of the valley near Deanich Lodge, and for a mile and a half below this place. On Cail Mhor, west of the above crags, the beds seem to dip below those at Deanich, and are more massive, with abundant indications of false-bedding, the minor laminæ being frequently disposed in irregular curves, while the main bedding planes, a few inches above and below these, are quite regular; indications of small clastic grains of felspar are not common, but have been occasionally observed; so also have thin streaks of heavy sediment, including many grains of black iron ore.

North-east of the Deanich Lodge sub-flaggy schists, and apparently coming in above them, we find in Gleann Mor other schists which are rather less massive than those of Cail Mhor and show much more distinct indications of clastic grains, as is well seen in various stream sections between a mile and three miles E.N.E. of Meall Dionach. The grains are often distinctly elongated, and their strike usually varies from 20° to 40° west of the dip of the foliation planes, which is slightly east of south. This Glenmore group of schists shows its clastic origin more and more evidently as we proceed in the direction of dip, where it joins on to the pebbly schists of Dunan Liath, Carn Feurlochain, etc., already described by Dr. Crampton in the Strath Vaich district.

Thin layers and lenticles, rarely more than an inch or two thick, which weather into hollows and are probably somewhat calcareous, are not uncommon in some of the siliceous schists, as, for example, in the crags a third of a mile south-east, and again 200 yds. north of Loch Sruban Mora. At the top of the crags half a mile E.N.E. of Lochan nan Leac a calcareous quartzite attains a thickness of 5 in.

Dyke-like pegmatites, with red felspar and white mica, occur in the siliceous series in the crags south and south-west of Loch Sruban Mora. Several of these attain a breadth of three feet, and can be traced 100 yds. in a direction slightly north of west, almost at right angles to the local strike of the foliation of the schist.

Thick quartz veins are perhaps rather less common in the siliceous schists than in the pelitic, but some big blocks of white vein-quartz seem nearly *in situ* in a siliceous area on the south-east side of Carn Ban, and are locally reputed to have given this hill its name, the Gaelic word "ban" meaning "white". The blocks indicate a vein about six feet broad running N.N.E.

Siliceous schists, in a soft disintegrated condition like that already noted in the Strath Vaich district, are also seen in the district now being described, for instance, in the upper, east and west, portion of Alltan Dubh Mor, and in the eastern crags of An Socach.

The most common type of schist in the broad pelitic band is a

garnetiferous mica schist containing both muscovite and biotite in fairly large flakes. The garnets are usually about the size of a pin's head and always less than a pea, and they were evidently in existence before the schist-making movements ceased, being often bordered at two opposite sides by " tails " of quartz. In the area, between a mile and a mile and a half south-west of Loch a' Choire Mhoir, these tails strike nearly south-east, while the direction of the dip of the foliation is almost E.S.E. It is not clear whether the force which led to the dragging away of the rock matrix from the garnet, and to the consequent growth of the quartz tails, came from the north-west or the south-east.

In the least sheared pelitic hornfels and the fine-grained pelitic schists which occasionally border the granitic gneiss the original bedding is unusually distinct, and there is often a close lamination (Plate III.), thin, rather sandy streaks alternating repeatedly with others of more pelitic character.

Bands of decidedly siliceous character occur in fair number within the broad pelitic band, but they are for the most part too small to be indicated on the one-inch map. The broadest examples occur near the north-west margin, on either side of the Coire Mor fault, and seem identical in character with the siliceous schists which occur *en masse* a little further north-west.

Besides the comparatively broad siliceous bands referred to in the preceding paragraph, there are also much thinner siliceous seams, rarely more than a few inches thick, which possess a very white matrix containing garnets and either biotite, in large flakes, or hornblende. These are intimately associated with other thin seams, seldom more than half an inch or an inch thick, and of a dark grey colour, which contain numerous prisms of zoisite, and are undoubtedly similar to the zoisite-bearing seams already described in the Strath Vaich district. These peculiar seams are perhaps best seen near Toll Lochan and in the S.S.E. course of the burn that passes about a mile south-west of Loch Coire Mhic-mhathoin. The zoisite is unusually abundant and distinct, in prisms often half an inch long, in a small exposure about 400 yds. N.N.W. of the outlet of Toll Lochan. In another exposure, about 300 yds. E.N.E. of the outlet, some bands are nearly half made up of garnets, while others contain small stellar clusters of hornblende. In a third locality, rather more than 400 yds. slightly east of south of the outlet, the thin hornblendic seams are repeatedly folded along axial planes inclining south-east, and the hornblende prisms lie, not along the bedding, but parallel to the axial planes of fold.

Besides the main pelitic band, we may mention also a few other pelitic exposures of some importance, which occur in the following localities: on the south-west side of the Coire Mor fault, a mile south of Toll Lochan; at the west side of Lochan nan Leac; in Alltan Dubh Mor, three-quarters of a mile above the foot; Creag Riabhach. The bands in the second and third localities probably unite to form one band in an area greatly obscured by drift, and the Creag Riabhach beds may also form an outlier of this band. In none of these localities have we noticed seams bearing hornblende and zoisite like those described in the main pelitic band. On the other hand, such seams have been detected in a minor pelitic band on the east side of Toll Lochan, and in another one in the crags a third of a mile N.N.E. of Glenbeg

house. Small garnets are common in the band on the south-west side of the Coire Mor fault a mile south of Toll Lochan, but have not been noticed in the other minor crops enumerated.

In a few localities, in the broad pelitic band, thin, rather coarse quartzofelspathic streaks, often spoken of as pegmatites, are tolerably abundant. They are for the most part parallel to the foliation and folded with it, but are often very short and lenticular. They have often been regarded as segregation products. In one locality, about half a mile south-east of Toll Lochan, these streaks perhaps make up a thirtieth part of the rock mass over a considerable area, and in portions of the crags two-thirds of a mile N.N.W. of Glenbeg house they make perhaps a tenth part. Similar streaks occur also in certain of the thinner pelitic schists, for example a quarter of a mile north and half a mile N.N.W. of Loch Sruban Mora, even where none of the adjoining siliceous schists contain any. Most of the thin pelitic bands do not, however, contain any of these pegmatitic streaks, and they are also of somewhat finer grain and darker colour than the schists of the broad band.

Some of the especially thin micaceous layers, often less than a quarter of an inch thick, are almost made up of large spangles of white mica, lying in various directions but usually at a considerable angle to the bedding and the foliation in the adjoining schists. Good examples of these spangle schists are seen in the burn nearly a mile south-west of the outlet of Loch na Gabhalach Nodha, and in another burn nearly three-quarters of a mile north-west of this outlet.

In some pelitic schists spots of water-clear felspar which are quite free from granulitisation and deformation, and cannot therefore be regarded as clastic grains, are tolerably abundant, though perhaps never larger than a pea. They are seen, for instance, in the following localities: west side of Lochan nan Leac; tops of the crags, a third of a mile N.N.E. of this lochan; Alltan Dubh Mor, three-quarters of a mile above the foot; a third of a mile slightly south of east of Loch Sruban Mora; about a quarter of a mile north-east of the outlet of this loch; the Abhuinn a'Ghinne Bhig, rather more than a mile and a quarter west of Deanich Lodge. In specimen 10371, from the locality near Loch Sruban Mora, the water-clear felspar has been examined by Dr. Flett and been found to consist of albite:* it contains inclusions of quartz and felspar, and small scales of biotite which are occasionally bent.

In the broad pelitic schist in the area south and south-east of Loch a' Choire Mhoir, veins of opaque white quartz, sometimes as much as six feet thick, are tolerably abundant, striking N.N.E. much the same as the foliation planes. Close on the east side of the burn nearly a mile W.N.W. of Glenbeg house, a quartz vein is as much as 12 ft. broad, but it cannot be traced far: the sides appear to have been slightly sheared.

On the west side of Bodach Beag, where the general dip of foliation is E.S.E., strong joints incline W.N.W. perhaps at 70°. Near Loch Coire Mhic-mhathoin the foliation dip is much the same as near Bodach Beag, but the main joints in the former place incline N.N.W. at 50°

* See also last paragraph in the description of the district of Glen Calvie and Cnoc nan Sac (p. 37).

or 60°. In the lower part of Allt Bheargais, a little W.N.W of Deanich Lodge, prominent joints incline west, perhaps at 35°, almost directly opposite to the dip of the bedding and foliation.

C. T. C., C. B. C.

DISTRICT OF GLEN CALVIE AND CNOC NAN SAC.

This district includes nearly all the area (within this one-inch map), which drains into the river Carron below the foot of Alladale River. Its eastern boundary is drawn through Carn an Liath-bhaid and Creag na Ceapaich.

It includes two main bands of pelitic or semipelitic character, which generally dip steeply south or S.S.E. These are separated by a belt of siliceous schist about two miles in breadth, in which the apparent general dip, or dip of limbs of isoclinal folds, is also S.S.E. The schists of sedimentary origin thus usually appear in this district to underlie the igneous complex on their south side, but it is to be noted that near the granite margin at Carn Salochaid the dip is sometimes steeply north instead of steeply south. The northern pelitic band, which we may call the Glen Calvie band, is a continuation of the main pelitic band already described in the district of Gleann Beag, etc. The southern or Diebidale band is as much as a mile broad in the eastern portion of the district, and, save where it is displaced by faults, it continues all along the margin of the Carn Chuinneag granite, excepting at the south-western end, where it appears to be gradually cut out between the granite and the siliceous schists further north. It is often in a hornfelsed condition, especially on Cnoc nan Sac and in the burn to the south-west, in certain areas which escaped more or less completely the isoclinal folding movements which converted the neighbouring rocks into schists. The main areas of the hornfelsed pelitic sediments are distinguished on the map (see also Plate XII.), and detailed descriptions of their characters and of their relations to the schists are given in Chapter V.

The Glen Calvie pelitic schist is never so much as a quarter of a mile broad, and near the foot of the glen it appears to be shifted northward, right out of the map, by a series of faults striking nearly north. The most westerly of these faults shifts the south margin of the crop nearly 700 yds.—the east portion towards the north—the direction of displacement to be expected from a fault with downthrow to the east. The breadth of the crop east of the fault is hardly half that on the west—a fact which may, perhaps, be best explained on the supposition that the crops on each side represent sections taken at different levels across an isoclinal anticline, the narrower crop being that at the higher level, on the downthrow or eastern side. There is some difficulty, it is true, in supposing the siliceous schists on either side of the Glen Calvie band to be on the same horizon, because those on the south side, for a breadth across the strike of about a quarter of a mile, are considerably whiter and poorer in mica than those on the north, and might, indeed, be called quartzites. But this difference may be due to rapid changes in the character of the sediment in adjoining localities. The most easterly of these Glen Calvie disturbances displaces the margin of the granite, the eastern portion towards the north, for about a mile, and is probably continuous with the

Strathconan fault, which has been traced through one-inch maps 83 and 82.*

The Glen Calvie band never shows any indications of hornfelsing, but it is indistinguishable from some of the more schistose parts of the Diebidale band. For various reasons, already mentioned in describing the district of Loch Glass, etc. (pp. 23, 24), it is not supposed to represent a folded portion of the Diebidale band. As an additional reason, it may be mentioned that the siliceous schist on its southern margin does not match well with that on the northern margin of the Diebidale band. Siliceous seams containing hornblende and zoisite, like those described in other districts, are well seen in the Glen Calvie band on the west side of the faults nearly a mile south-west of Glen Calvie Lodge. The analysis of one of these seams is given in Chapter III. In one place a thin hornblendic seam crosses the bedding, and probably represents an old calcareous vein which has been metamorphosed.

About half-way between the two big pelitic bands comes a zone, often about half a mile broad, in which indications of clastic grains are unusually clear. The northern margin of this zone seems fairly well defined all the way from Glen Calvie, which it crosses rather more than a mile and a third above the foot, to the western limit of the district, where it runs about a quarter of a mile north of the top of Leac Ghorm, but it should be stated that equally distinct clastic grains have been observed in two localities which lie considerably further north, namely, in the burn a mile and 200 yds. S.S.E. of Carn na Speireig, and again two-thirds of a mile south-east of this hill. The zone is evidently faulted by the big disturbance, already referred to, which runs along Glen Calvie, but reappears on the east, in Garbh Allt (Fig. 10), about three-quarters of a mile north-west of Cnoc nan Sac, and has been traced considerably further north-east, outside the limits of the map. In the section referred to in Garbh Allt, certain of the quartz pebbles have been pulled out to the length of an inch and a half, though they are only a quarter of an inch broad: the direction of the stretching lines is N.N.W.-S.S.E., while the dip of the foliation planes is nearly S.S.E. On the west side of the Glen Calvie big faults the stretching of the clastic grains is also well seen in many localities, but its direction here differs considerably from the direction of the dip of the foliation, which is still S.S.E. At the western end of the district the clastic character is still more prominent, and is especially well seen in some crags nearly half a mile slightly south of east of Dunan Liath, where the beds appear to be unusually little sheared. It is to be noted that these crags are about a mile north of the granite boundary, and are separated from it by schists which show little or no clastic characters. The zone which is specially pebbly appears to be 50 or 60 ft. thick, and contains seven or eight seams, each a few inches thick, which are full of pebbles from half an inch to an inch and a half long. Some of the larger specimens are finely granular and resemble quartzite, while others are of reddish quartz, and show little or no granulitisation. A few bear some resemblance to red jasper. Many of the smaller specimens consist of bluish opalescent quartz or of reddish felspar. The strata are very false-bedded, and show but little evidence of schistosity. The more schistose beds outside the zone contain laminæ rich in grains of epidote and iron ore—heavy minerals which would

* For further details see Chapter IX. of this Explanation.

naturally fall together in the course of deposition. The iron ore, consisting of hæmatite to a large extent, appears to have been recrystallised, and sometimes forms a matrix enclosing round grains of quartz. The laminæ specially rich in iron ore are lenticular, and are often confined to small shallow basins, from two to ten inches long, which probably mark little hollows in which the heavier sediments settled originally: their concave surfaces face upwards; so that it is probable that the beds here, which dip S.S.E. at about 60°, are not in an inverted position.

A good many siliceous beds are found within the Diebidale pelitic zone, but only a few are large enough to be shown on the one-inch map. They are whiter and contain less mica than the siliceous beds just north of the zone, and cannot, therefore, be considered folded-in portions of it. One of the siliceous bands, dipping about 70° on the east side of Mullach Creag Riaraidh, is 60 yds. broad, and another, at a gentler angle, makes a big crop a little south of Cnoc nan Sac.

The Glen Calvie pelitic band contains thin seams bearing garnet, hornblende and zoisite (like those already described in other districts) on the hillside nearly a mile south-west of the foot of Glen Calvie; and it shows, too, in addition, rather more than a mile slightly north of east of Carn na Speireig, several thin hornblendic seams which cross the bedding, and perhaps represent old calcareous veins. The Diebidale band also includes thin laminæ containing garnet, hornblende and zoisite, which are well seen nearly a mile north-west of Carn Bhren.

Spots, rather less than small peas, of undeformed water-clear felspar, are tolerably common in several thin bands of pelitic or semi-pelitic schist just outside the margins of the Glen Calvie band. In both the specimens sliced (10916 and 10917) Dr. Flett found this new felspar to consist of albite.* C. T. C., C. B. C.

* See also the description of the district of Gleann Beag, etc. (p. 34).

CHAPTER III.

PETROLOGY OF THE MOINE SCHISTS.

These Moine gneisses and schists include several types of metamorphic rocks. One group comprises the granulitic gneisses which were originally arkoses and felspathic sandstones, together with the quartzites and quartz schists and certain conglomerate gneisses. A second group of argillaceous rocks is now represented by mica schists and micaceous gneisses; and there are also a small number of rocks that contain calc-silicate minerals, such as zoisite, and were originally calcareous shales or marls. Examples of these classes are found over the whole area occupied by the Moine Series. They often show clastic structures, such as bedding and pebbles, but for the most part are very highly metamorphic, and the more crystalline sedimentary gneisses within this Sheet could be very exactly matched in almost any part of the great area covered by this system in the North of Scotland.

GRANULITIC (PSAMMITIC) GNEISSES.

The quartzofelspathic granulites or granulitic gneisses are well banded, rather fine-grained rocks which have in the field a certain resemblance to bedded micaceous sandstones. They consist essentially of quartz, felspar and mica. Biotite alone is present in some of them, but most contain muscovite also. The micas are not usually arranged in discrete folia but are scattered through the rock: they lie between the grains of quartz and felspar, but the edges of the plates may pierce either mineral, as has been pointed out by Dr. Teall.* The parallel orientation of the micas is usually perfect: thin micaceous folia often occur several inches apart, and weathering along these seams produces the flaggy appearance often visible in cliff and stream sections. Between these micaceous laminæ the rock may be nearly homogeneous or only faintly banded. The splitting surfaces of the "flags" are usually coated with thin films of mica. The biotite has a pleochroism from yellow brown to deep brown or nearly black. It is uniaxial, never eumorphic, and weathers to chlorite. White mica may be in parallel growth with the black mica, but more usually occurs separately. In some rocks the muscovite forms rather large irregular flakes that are not orientated along the foliation planes, and enclose small grains of quartz, felspar, etc. The quartz, which is full of fluid cavities, occurs in small anhedral grains intermingled with the felspars. One of the most characteristic features of the Moine granulites is that neither quartz, felspar, nor mica show any marked tendency to segregate into distinct folia. Hence in micro-

* 'The Geological Structure of the North-West Highlands of Scotland,' *Mem. Geol. Survey*, 1907, p. 600.

scopic sections they often appear nearly massive, and the orientation of the mica flakes is almost their only striking metamorphic feature. The felspars are orthoclase, albite and oligoclase. Orthoclase predominates, but albite and oligoclase are probably always present and are sometimes rather conspicuous. The oligoclase is usually polysynthetic, the albite and orthoclase untwinned, but all the felspars may be entirely free from striation between crossed nicols, and then the oligoclase is recognised only by its refractive indices, measured against adjacent quartz grains; while the albite is distinguished from the orthoclase by its stronger double refraction and positive sign in convergent light. In the Moine granulites of some districts microcline is by no means scarce, and Mr. Barrow * has described its abundance in the area to the west of Glen Tilt, but microcline is strikingly rare in the sedimentary gneisses from this area. Simple, untwinned orthoclase, on the other hand, sometimes forms more than one-half of the quartzofelspathic granulites.

The accessories which are always present are apatite, iron oxides and zircon, only the latter being in good crystals. Rutile is occasionally seen; pyrites more frequently, and a little calcite occurs now and then, wedged in between the quartz and felspar. Sphene in very minute granules (sometimes poikiloblastic) is by no means uncommon. Tourmaline is very unusual. One of the most interesting features of these Moine gneisses is the frequent presence of lines of heavy minerals, zircon, iron oxides (and sphene after ilmenite), rutile and epidote, which indicate original laminæ of sedimentation. The dark bands are narrow, sometimes wavy, and often cross the foliation as indicated by the disposition of the plates of mica.

Many of these rocks are garnetiferous, though the garnets are not as a rule very abundant or conspicuous in the hand specimens. They are small, pale pink in section, usually rounded, with occasional traces of angular boundaries indicating crystal facets. They are often filled with minute inclusions of quartz, iron oxides, etc. Hollow or skeleton crystals also are seen forming a narrow rim around large grains of quartz and felspar. Minute granules of zoisite and epidote, though not abundant, are fairly common.

In a typical Moine quartzofelspathic granulite all the important minerals are about equidimensional. The quartz and felspar form a granular aggregate; the felspar as a whole tending to crystallise around the quartz, so that of the two it has rather the more irregular shape. The mica forms plates parallel to the foliation. There is no clastic or psephitic structure; and except in the micas no tendency to elongation in a definite direction; porphyroblastic (pseudo-porphyritic) structure is evinced only rarely by garnet, muscovite, albite and microcline, when present in exceptionally large crystals; micrographic (or myrmekitic) aggregates of quartz and felspar are exceedingly rare. There is also little tendency for any of the commonest minerals (except garnet) to enclose grains of the others. Hence these rocks are typical illustrations of granoblastic, homœoblastic structure. They were completely recrystallised in the solid state with obliteration of original textures, their minerals having developed

* G. Barrow, 'On the Moine Gneisses of the East-Central Highlands, and their Position in the Highland Sequence,' *Quart. Jour. Geol. Soc.*, 1904, vol. lx. p. 406.

simultaneously. The prime minerals of these rocks are such as are stable under "regional" metamorphism; hence there has been little alteration in the mineral composition, but every grain of which they consist is new in the sense that it has been formed during the metamorphic process. Cataclastic structures are strikingly rare in the more felspathic granulites; tailed aggregates of quartz, crush belts and strained quartzes are seldom seen. Movement must have taken place through the whole rock, but so slowly that the finer crushed material was removed by a building-up process, being dissolved by interstitial water and deposited on adjacent grains of similar composition. Moreover, after folding was over, the temperature probably remained for some time so high that a process of slow growth went on, which finally obliterated all traces of "mortar structure" or detrition of the component grains.

QUARTZITES, QUARTZ SCHISTS.

Rocks of a more siliceous type occur also in this district as in many other portions of the Moine country. They have been described from the Cromdale Hills by Mr. Hinxman,* from the north-west edge of the Moines by Dr. Horne, Mr. Clough and Dr. Teall,† from the Tilt Valley and Deeside by Mr. Barrow,‡ and from Central Perthshire by Mr. Grant Wilson.§ Many of them contain a little biotite, but muscovite is more abundant in the majority and makes the rocks slightly fissile. The felspars are mainly orthoclase, and the accessories the same as those enumerated in the quartzofelspathic granulites. Heavy bands occur in these rocks also, and are often very obvious from their dark colour in hand specimens. The quartz appears to recrystallise less readily than the felspar, for evidence of strain and cataclastic structures occur frequently.

CONGLOMERATES (CONGLOMERATE GNEISS, PSEPHITIC GNEISS).

Several localities are known in this Sheet where conglomerates (more or less foliated) occur among the Moine gneisses. The principal localities are the south end of Lochan Gobhlach, half a mile south-west of Dunan Liath, the Crom Loch and Beinn a' Chaisteil. Within the aureole of the Carn Chuinneag augen gneiss many of the hornfelsed Moine rocks have their original pebbly structures preserved, but none of them is so coarse as to be conglomeratic.

The pebbles of the conglomerate schists may be well rounded and an inch or more in diameter. Where the rocks are least crushed and the rounded form of the pebbles is maintained, the quartz forms a coarse mosaic under the microscope; where shearing has been more powerful and the pebbles are flattened or lenticular, they break up

* 'Explanation of Sheet 75, Scotland,' *Mem. Geol. Survey*, 1896, p. 17.

† 'The Geological Structure of the North-West Highlands of Scotland,' *Mem. Geol. Survey*, 1907, p. 599.

‡ *Op. cit.*

§ 'The Geology of the Country round Blair Atholl, Pitlochry and Aberfeldy,' *Mem. Geol. Survey*, 1905, p. 71.

in polarised light into small areas with interlocking borders, occasionally giving undulatory extinctions. Examples can also be found in which they have passed into lenticles, that lie parallel to the foliation of the gneisses and begin to blend with the matrix. The quartz sometimes contains scales of white mica (quartz schist); it is always, however, free from felspar. Most probably it has been derived from quartz veins, though there is a possibility that some of it may represent the quartz of very coarse granites or pegmatites. A few pebbles of quartz felsite have also been detected. The felspar pebbles are usually less numerous than those of quartz. They are microcline, albite or orthoclase, each grain being simple and consisting merely of a worn crystal. Though less often flattened or sheared than the quartz, they are occasionally crossed by narrow threads of granulitic material. In some cases the felspars are filled with finely granular epidote; in others they contain much white mica. The other pebbles are fine quartzofelspathic granulites usually with muscovite and not biotite, resembling closely the finer psammitic gneisses of the Moine complex. The only schistose fragment collected is a dark, well foliated pebble rich in laminar iron oxide which may be a hæmatite mica schist or a fine itabirite. It is rather unfortunate that the nature of these pebbles throws very little light on the geology of that formation, older than the Moine rocks, from which they were derived.

The matrix of the conglomerate gneiss, often very scanty in amount, is a granulitic aggregate of quartz, felspar and mica, usually siliceous and often containing a considerable amount of fine scaly muscovite. It is often rich in iron oxides, zircon, garnet, epidote, orthite and other heavy minerals. This is quite in accordance with its conglomeratic character, for coarse pebbly beds are exactly those in which we might anticipate the occurrence of deposits of minerals of high specific gravity. The zircon is only in small crystals and seems rounded by attrition. Garnet is not very abundant, and always of minute size. The epidote is finely granular: its frequency reminds us of the beds of the Moine Series that rest on the inliers of Lewisian Gneiss, and of the Torridonian epidotic grits. Although in part recrystallised, it is often an original constituent, as is shown by the rounded shapes of its crystals, which resemble those of the quartz and felspar pebbles. Brown grains of undoubted orthite occur in some of these rocks, and very frequently the minute epidotes have brown cores which cannot be proved to be orthite because they are too small. This recalls the abundance of orthite * in some of the epidotic gneisses of the Lewisian inliers and the adjacent Moine rocks. Iron oxides, principally magnetite, are also strikingly common: in many specimens the matrix of schist which cements the pebbles is rendered nearly opaque by them. That they are of clastic origin is sufficiently clear from their abundance and their distribution in bands which represent original bedding planes. The occurrence also of a pebble of iron schist is significant. It is curious that they do not show borders of sphene; this may be due to their containing little titanium. No rutile and no cassiterite have been noticed in the slides.

* J. S. Flett, 'On the Petrographical Characters of the Inliers of Lewisian Rocks among the Moine Gneisses of the North of Scotland,' *Summary of Progress of the Geological Survey* for 1905, p. 159.

PELITIC SCHISTS AND GNEISSES.

These rocks, which represent the shales and arenaceous shales of the original Moine formation, are mica schists and micaceous gneisses, highly metamorphic. Their foliation is very perfect, owing to the abundance of mica with a well marked parallel arrangement (Plate IX., Fig. 4). When quartz and felspar form a considerable part of the rock, they are aggregated into lenticular folia surrounded by continuous films of mica. As a rule the foliation is of a plane or linear type, and the splitting surfaces are flattish ; in some, however, the foliation is undulose, and the schistosity is of the crumpled type. Spots of authigenic felspar and pink garnet crystals are often visible in the hand specimens.

The muscovite is colourless, or shows faint greenish pleochroic halos around inclusions of zircon, etc. The biotite has colours changing from clear yellow to dark brown, nearly black, as the polariser is rotated, with pleochroic halos strongly marked. These two minerals, though often lying side by side, do not as a rule form parallel growths. Pale green chlorite (with dark blue and brown polarisation tints) occurs in small amount and is presumably secondary. The quartz and felspar are in transparent subangular grains. Orthoclase and microcline are rare or absent ; most of the felspar is albite, with occasionally oligoclase. As a rule the albite is untwinned. Garnet occurs in many of the rocks, usually in small crystals, which may be nearly euhedral. It is pale pink and contains many small dark inclusions (iron oxides or graphite), which make it semi-transparent and greyish-coloured. Spots of quartz and flakes of mica are common also in the garnets. Iron oxides in grains and in plates parallel to the foliation, apatite and zircon, are always present. Pyrites, minute yellow grains of epidote or zoisite, sphene and rutile, are occasional accessories. The coarser rocks are muscovite biotite gneisses that have well marked folia of quartz and felspar, but differ little in minerals or in structure from the mica schists.

Besides the larger porphyroblastic crystals of garnet there are sometimes white spots of albite felspar. These crystals look like clastic grains, but are authigenic ; they never show idiomorphism, but at their margins inosculate with the other rock components ; often they are untwinned, but their positive sign shows that they are not orthoclase. Simple albite-twinning occurs most frequently, with occasional pericline bars. Frequent enclosures of rounded quartz, minute epidotes and scales of biotite, give these large crystals a poikilitic character. Very rarely large biotite flakes may be seen.

ZOISITE GRANULITES AND ZOISITE HORNBLENDE GNEISSES.

In the Moine rocks there are bands in which zoisite is an essential and very characteristic mineral ; it may occur only in small quantity or may form nearly one-half of the rock. Two fairly distinct types can be recognised ; in one the zoisite occurs only in minute grains, invisible to the unaided eye, and the rock has much of the appearance of the nearly massive quartzofelspathic granulites ; in the other the

zoisite forms long, grey blades running through the matrix, and conspicuous on weathered surfaces. They have often no definite orientation parallel to the foliation.

The fine-grained granular or granulitic type is known to occur in many widely scattered districts. It was recognised at Ballindalloch, on Speyside, by Mr. Hinxman, and its microscopical characters have been described in the memoir on Sheet 85.* Mr. Barrow has found it in the Moine gneisses of North Perthshire and Aberdeenshire,† and has published an excellent photomicrograph of a section of one of these rocks. This fine-grained type occurs also near Spean Bridge, in Western Invernesshire, where they were mapped by Mr. Grant Wilson and described by Dr. Teall,‡ and representatives of this group are known in the Ross of Mull at the extreme south-west limits of the distribution of the Moines. Many of them have a pale grey colour and an irregularly blotched appearance: as these are tough and not markedly fissile they are extensively used for road metal in some parts of the Highlands. Under the microscope they consist of quartz, felspar, garnet, zoisite, hornblende and biotite. The quartz is similar to that of the other granulites. The felspar is partly clear, untwinned orthoclase and albite, but includes also polysynthetic oligoclase and andesine, all in minute anhedral grains, forming a typical granoblastic mosaic. The garnets are sometimes large and of very irregular shape, filled with enclosures of quartz and felspar; at other times they are small and nearly free from inclusions, but even the small crystals are rarely eumorphic. In section they are pale pink to colourless. The zoisite crystals vary in size from ·3 millimetre to minute granules. They rarely show crystalline outlines, and are never eumorphic: the largest contain inclusions of quartz, etc.: the smallest are enveloped in the other minerals of the rock. Pale grey and dark blue are the usual polarisation tints, but the outer edges of some crystals may give yellows like those of epidote. There are also cases in which these grains have a feebly polarising brown centre, which may be orthite. The biotite differs from that of the ordinary granulites only in being of paler brown colour and less intensely pleochroic. Muscovite is seldom seen. The principal accessories are zircon, colourless or brownish sphene, iron oxides and apatite. Some of these rocks also contain a little calcite in small anhedral crystals filling spaces between the quartz and felspar. This, together with the occurrence of soda-lime felspars in fair quantity, is, in fact, one of their best marked peculiarities.

The hornblende is pale green or greyish green, having the colours usually ascribed to actinolite. It occurs as short prisms, never bounded by good crystalline faces, and enclosing quartz, felspar and other minerals.

The coarse-grained rocks of this group, with large bladed crystals of zoisite and hornblende, are known only from the northern and western portion of the Moine area. They were first observed by Mr. Gunn and Dr. Horne in the Fannich district, and were described by Dr. Teall.§ An excellent example of this group occurs among the

* 'The Geology of Lower Strathspey,' *Mem. Geol. Survey*, 1902, p. 46.
† *Quart. Journ. Geol. Soc.*, 1904, vol. lx. p. 410.
‡ *Summary of Progress of the Geological Survey* for 1899, p. 40.
§ *Summary of Progress of the Geological Survey* for 1898, p. 13.

pelitic schists on the hillside about three-quarters of a mile south-west of Glen Calvie Lodge, forming narrow bands of dark grey colour with large white zoisite crystals (an inch in length) lying irregularly in the foliation planes. These zoisites are narrow, but in cross section are idiomorphic, showing the usual faces.

They are spotted with enclosures of quartz and other minerals. In polarised light their interference colours are light or dark grey with straight extinction, and often the double refraction is variable, so that between crossed nicols the sections have a flaked or streaked appearance. These large prisms have a comparatively small axial angle (2 E. about 40°), and the acute bisectrix is positive. The optic axial plane is parallel to the direction of elongation; hence the lath-shaped sections are all negative. These properties show that this mineral belongs to zoisite α, but the axial angle is rather small. In similar prisms from other rocks of this group the angle diminishes till a nearly perfect uniaxial cross is obtained in convergent light. The positive sign is retained.

Another variety of zoisite, also colourless and non-pleochroic, is very abundant in these rocks, but occurs principally as small prisms in the groundmass. These have very rarely any trace of crystalline form, so that the optical orientation is not easily made out. This variety, however, can readily be distinguished by its behaviour in polarised light, as its interference colours are always indigo-blue, often in extraordinarily vivid shades. It has a wide axial angle, is optically positive, and has the optic axial plane transverse to the elongation. Hence the sign of lath-shaped sections may be positive or negative. Oblique extinction and simple twinning were not observed in this mineral, but it has often a very marked zonal structure, the outer portions having a higher double refraction than the inner. This is apparently a form of clinozoisite. Occasionally it surrounds the larger blades of zoisite, forming a narrow border.

The hornblende is greyish green, and occurs also in long narrow crystals, though they are not so numerous or conspicuous as those of zoisite. The pleochroism is, on the whole, feeble, $X=a$, yellow, $Y=b$, grey-green, $Z=c$, green, and the extinction angle $Z-c$ is about fifteen degrees. Occasionally there are traces of eumorphism in the prism zone, but most of the crystals are irregular. They contain, like the zoisite, very numerous enclosures of the other minerals of the rock. The hornblende also has marked pleochroic halos around small enclosed epidotes and zircons.

Garnets are very numerous in some of the bands; they are small, nearly eumorphic, and enclose grains of quartz and black dusty iron oxides or graphite. The other elements of this rock are quartz and albite, forming a groundmass for the larger crystals of zoisite, hornblende and garnet. Biotite is usually absent, as in some of the Moine rocks of this group described by Dr. Teall; calcite and oligoclase also are not present in the section. A fine-grained micaceous secondary mineral, probably after felspar, often mingles with the zoisite, but its nature and origin are not entirely clear. Apatite, zircon and iron oxides represent the minor accessories; the latter are often surrounded by yellow rutile, a fact which is somewhat remarkable, seeing that the abundance of lime-silicates would have led us to anticipate rather the formation of sphene.

SiO_2	62·55
TiO_2	·79
Al_2O_3	15·75
Fe_2O_3	1·56
FeO	3·26
MnO	·28
(CoNi)O	·04
CaO	9·39
BaO	trace
SrO	·05
MgO	2·88
K_2O	1·54
Na_2O	·93
Li_2O	trace
H_2O at 105° C.	·15
H_2O above 105° C.	·64
P_2O_5	·30
S	nt. fd.
CO_2	trace
Total ..	100·11

Garnetiferous zoisite hornblende granulite (11798), on hill ¾ mile south-west of Glen Calvie Lodge (anal. Dr. W. Pollard).

A complete analysis of this rock, executed by Dr. Pollard, is given above. This shows that it was really a siliceous marl: it contains only 9·39 per cent. of lime, and this corresponds to about 17 per cent. of carbonate of lime, if we assume, as we seem entitled to do, that this was the form in which it originally occurred in the rock. The alumina is sufficiently high to show that the rock has affinities with the shales, though it is of rather a siliceous type. This analysis settles the origin of the lime in these rocks: it was always doubtful whether, especially in those which contained least zoisite, it might not have been due to clastic plagioclase; but the ratio of lime to soda shows that in that case the soda-lime felspar must have been anorthite, which is a far from probable explanation. The small amount of soda (less than one per cent.) is very significant: it is less than in the shales. The almost complete elimination of the carbonic acid is a fact of great interest. It would seem to imply that metamorphism had taken place at a fairly high temperature, but this cannot be ascribed to the proximity of the augen gneiss, as the rock analysed lies outside the aureole, and similar rocks occur in other parts of the sheet where no intrusions are known.

Other excellent examples of these rocks are 10374 (from 4700 ft. south-west of Loch Coire Mhic-mhathoin), 10397 (from 5000 ft. from Carn Bhren, between north-west and W.N.W.), and 10375 (1300 ft. slightly west of north of outlet of Toll Lochan). In some of them there is a banding due to predominance of zoisite with quartz in certain folia, and of hornblende and garnet in others. J. S. F.

CHAPTER IV.

FIELD RELATIONS OF THE OLDER IGNEOUS ROCKS.

Introduction.

In this chapter will be described all those intrusive igneous rocks which are as a rule well foliated, and which have been intruded into the sediments before the transformation of the latter into schists was completed. A few thin bands of lamprophyre, mica trap and basic rock that are also sheared to a variable extent will be reserved for Chapter VIII., as these seem to have been sheared by movements special to themselves, which did not affect the neighbouring sediments to any great degree. There is, however, it is admitted, some doubt whether certain intrusions should be classed with the Older or the Newer Igneous rocks.

The rocks to be described may be divided into four main groups, as follows :—

- Plutonic
  - i. Basic. Diorite, Epidiorite (representing Gabbro, foliated and unfoliated).
  - ii. Acid. Granite, Aplite, Pegmatites, etc., foliated and unfoliated. The foliated types are often represented by a beautiful Augen Gneiss—the "Inchbae Rock."
  - iii. Garnetiferous Albite Gneiss with Magnetite and Tinstone.
- Minor Intrusions
  - iv. Basic Dykes and Sills, generally in the form of Epidiorite, Hornblende Schist or Chlorite Schist. Separable into two divisions, namely :—
    - A. Intrusions in the Moine Rocks.
    - B. Intrusions in the Plutonic Masses.

It is the rule in this district, as in so many others, that the basic plutonic rocks consolidated before the acid.* Not only did the rocks of group i. solidify before those of group ii., but within each of these groups it can often be seen that the darker, more basic varieties solidified before the paler : thus the biotite gneisses of group ii. are frequently cut by veins of pale muscovite gneiss and granulitic aplite.

Nevertheless, after the consolidation of the acid plutonic rocks, a phase of minor intrusions supervened, as in Skye,† during which basic rocks were again irrupted in narrow dykes.

The garnetiferous albite gneiss, group iii., which contains cassiterite, is found only in Glen Diebidale.

The minor intrusions possibly include bands of very different ages. None of the epidiorites or hornblende schists found in the Moine schists can be shown to cut the plutonic masses, nor do they ever appear to become more numerous near them, as if they might represent apophyses from the basic parts. They have petrological resemblances to the

* Messrs. Dakyns and Teall, 'On the Plutonic Rocks of Garabal Hill and Meall Breac,' *Quart. Jour. Geol. Soc.*, 1892, vol. xlviii. p. 104. A. Harker, 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Survey*, 1904.

† A. Harker, *op. cit.*

FIG. 1. DIORITIC LUMPS INJECTED AND SURROUNDED WITH PALER GRANITIC ROCK. Half a mile west of Leaba Bhaltair.

FIG. 2 (× 3). GARNETIFEROUS PELITIC MICA SCHIST (SHEARED HORNFELS) WITH BENT AND PUCKERED PSEUDOMORPHS AFTER CHIASTOLITE. About 200 yds. S.S.W. of west end of Loch a' Chaoruinn.

basic intrusions of group iv. B., which cut the plutonic masses, but these are no greater than those they bear to some of the plutonic rocks themselves.

An unusually good exposure which shows the injection of a dioritic rock by granitic strings, both in a state perfectly free from foliation, is seen at the margin of the peat nearly half a mile west of the Ordnance Station on Leaba Bhaltair (Plate II, Fig. 1). The dioritic rock is fine-grained, and the dioritic inclusions within the granite are sharply defined and quite angular even when of the smallest dimensions. The granitic rock has a rather fine-grained matrix.

Of all these rocks the acid gneisses (group ii.) are the most extensive, and make the greater part of two large plutonic masses, as well as minor bands which in places form a fringe outside these. Both these large masses strike nearly north-east, approximately parallel to the sedimentary rocks at their sides. The largest one may conveniently be called the Carn Chuinneag mass, as it includes Carn Chuinneag (Plate XII.), one of the highest hills in the map. This mass extends from Carn nan Aighean in a north-easterly direction for about twelve miles, to Cnoc an Liath-bhaid, and its breadth is often about four or five miles. It is only in this Carn Chuinneag mass that basic plutonic rocks are recognised with confidence, and within it these rocks are specially abundant, as is shown in the map, near the central and south-western portions of its north-western margin. The margin near Cnoc na Tuppat and south of Cnoc nan Sac, and again on the south-east side near Carn Cas nan Gabhar and Kildermorie, is of a very complicated fringed type (Plate III.). It keeps for the most part to one geological horizon, a pelitic or semipelitic belt which is considered to represent the highest stratigraphical division of the schists in the district, but at the south-western end it comes into contact with siliceous schists which are probably on a lower horizon. On the north-west side of the mass the sedimentary rocks generally appear to be inclined south-east, as if they were dipping below the plutonic rocks, but on the south-east side the reverse relation is often found. It is allowable, therefore, to regard the mass as a huge laccolite occupying the centre of a syncline, the south-eastern limb of which is often reversed.

On the north-east side of Carn Bhren a considerable mass of granite is seen lying with an almost horizontal floor over somewhat sheared pelitic hornfels. The floor is almost parallel to the bedding in the hornfels, but is crossed by a foliation which affects granite and hornfels alike.

According to the view here adopted, that the Carn Chuinneag plutonic mass is a laccolite lying in a syncline, it is necessary to suppose that the two branches of the Loch Morie fault which displace the margin of the plutonic mass near Kildermorie are wrench faults—not normal faults with downthrows to the south-west—the latter being the view which might on first sight be adopted from a consideration of the effect of the fault on the Old Red Sandstone below the foot of the loch.

Denudation has probably considerably reduced the size of the laccolite, but how much farther it formerly extended it is impossible to say. It is to be noted that according to our theory the pelitic belt with which the margin of the mass is generally in contact is the

highest stratigraphical zone of the Moine Series in the map, and that its higher members never occur at a distance from the granite. It is therefore not surprising that the granite is not now found again north-west and south-east of the complex, even though its original extension may have been much greater than now. No plutonic rocks of groups i. and ii. are seen in the map in the two lowest members of the Moine Series, and the feeders of the Carn Chuinneag mass must, therefore, lie within its present boundaries. C. T. C.

The smaller of the two plutonic masses alluded to is about five miles long in a north-east direction and less than three miles broad. It includes the well-known augen gneiss of Inchbae,* and may be called the Inchbae mass. The margin of the main mass of this granite is surrounded by a fringe of minor intrusions both on the north-east side at Carn Mor, on the east side at Inchbae, and at the south end. They extend as far south as Loch Luichart, and are represented also on the west side of the big N.N.E. fault which passes by the head of this loch. It is noticeable that in the last mentioned locality the rocks west of the fault are impregnated with multitudes of thin veins of foliated granitic material,† while on the east side we find no similar crowd for some miles to the north. Possibly on the west side of the fault some great granitic mass may formerly have existed a little above the present ground surface. B. N. P.

This Inchbae mass lies south-west of that of Carn Chuinneag, and is only separated from it by an interval of about a mile and a quarter, most of which is occupied by Old Red Sandstone of later age than the granite. It is quite possible that it is connected with the Carn Chuinneag mass at no great depth by underground roots, and that it was also connected with it at the surface before denudation had advanced so far as at present.

Group iv., that of the foliated basic dykes and intrusive sills, is very widespread, but, as already stated, it includes two divisions which may be of different ages. The rocks of the division "A," that of the intrusions within the Moine rocks, are found in many different parts of the map, but they are perhaps specially numerous in the west and north-west portions and at the side of Loch Glass. Except in the last mentioned locality, however, the individual bands are rarely more than a few yards wide and can seldom be traced far.

The igneous rocks to be described in this chapter have suffered greatly from shearing, and it seems clear that most of this shearing took place after their consolidation was completed. In various granitic sills, forming part of the plutonic fringe, the shear-lines are not parallel to the margins of the sills but make considerable angles therewith,‡ being parallel to the axial planes of the folds which affect both sediments and igneous rocks alike. Near Inchbae the granitic rocks often show two distinct foliations, the second having evidently been formed by strain-slipping movements which contorted and broke through the first, and even if the first foliation could be attributed to shearing before complete consolidation the second could not be so.

Strong evidence that much of the shearing in the igneous rocks took place after their consolidation is also afforded by sections in

* *Annual Report of the Geological Survey* for the year 1896, p. 18.
† Dr. B. N. Peach, *Summary of Progress of the Geological Survey* for 1898, p. 10.
‡ This was first noticed by Dr. B. N. Peach, we believe. *Ibidem.*

Strings of Granitic Gneiss in Basic Gneiss. Diebidale River, south of Mullach Creag Riaraidh.

Glen Diebidale, in the river south of Mullach Creag Riaraidh, which show basic plutonic rocks of group i. invaded by granitic strings (Plate V.). The margins of the strings are not chilled, but they are well defined, often folded and crossed by a foliation—either plane-parallel or linear—which is common both to granite and diorite. Somewhat similar sections are also seen on Carn Salochaidh, where the augen gneiss is occasionally crossed by fine-grained strings resembling felsite or aplite. The foliation in the gneiss continues through the strings and often makes considerable angles with their margins.

In both the basic and acid plutonic rocks (groups i. and ii.) linear foliation or rodding is perhaps as common as plane foliation, but it is particularly well seen in the crags of rather fine-grained granitic rock about a mile west of the Ordnance Station on Leaba Bhaltair,* and in the dioritic rock in the river E.N.E. of Mullach Creag Riaraidh (Fig. 3). In these rodded rocks the constituents are arranged not in parallel folia but in parallel rods, and in sections taken at right angles to the rods we only see small, somewhat uniformly scattered spots, which represent the ends of rods. In some parts of the Highlands a structure of a similar appearance has been produced by the crumpling and strain-slipping of earlier foliation planes, which have thus been broken up into narrow rod-like portions, but for the structure in the Carn Chuinneag mass such an explanation does not seem applicable. We may suppose, however, that rodding can be produced in any cube of rock by subjecting it to equal pressures from four sides in opposite pairs, leaving the constituents to squeeze out, as it were, towards the other two sides, on which the pressure is less.†

Fig. 3 (× 1).—Hornblende Schist with Linear Foliation. Diebidale River E.N.E. of Mullach Creag Riaraidh.

At the beginning of this chapter it was stated that the Older Igneous rocks included all those which are as a rule well foliated. It will be seen in subsequent descriptions that in certain areas considerable portions, perhaps particularly of group i., have escaped foliation, even though, as Dr. Flett supposes, the original pyroxene has been largely changed into hornblende.

i. Basic Plutonic Rocks. Diorite, Epidiorite, Foliated and Unfoliated.

As already stated, the rocks of this group are only recognised with certainty near the north-west margin of the Carn Chuinneag plutonic

* It is believed that this name is more correctly applicable to the landslip north of this Ordnance Station.

† Grubenmann, 'Die kristallinen Schiefer,' 1904, vol. i. pp. 88–89.

mass. In their original condition they are said by Dr. Flett to have been gabbros, augite diorites and quartz diorites. They are never seen to form the actual margin, though they occur in places within 40 or 50 yds. of it. They compose several exposures about three-quarters of a mile south-east of Cnoc na Tuppat, and are well developed south-west of this locality, as far as a mile and a half beyond Loch na Glasa. No large exposures have been seen so far as a mile from the margin. Much the largest mass is that near the head of Glen Diebidale, which is probably nearly three miles long in an E.N.E. direction, parallel to the adjacent margin of the Carn Chuinneag complex, though never so much as half a mile broad. In the Inchbae plutonic mass it is not certain that any rock of group i. exists. The Glen Diebidale basic mass is excellently exposed both in the river and in various smaller streams and crags, but most of it is in a more altered, foliated condition than the smaller masses which are found to the south-west of it and also than some of those to the north-east, near Cnoc na Tuppat. In the view looking up Diebidale from near Mullach Creag Riaraidh the large area of basic rock makes a conspicuous contrast with the granitic rocks at its sides, as it gives rise to much greener and more grassy slopes and carries but little heather.

C. T. C.

The exposures of basic igneous rock occurring to the south-west and west of Loch na Glasa and north of Carn nan Aighean, are often isolated in the peat, but their relation to the surrounding granitic rocks is well seen in some cases although the areas are small, never exceeding 100 yds. in diameter. Good sections showing the relation of the rocks are also to be seen in the small burns feeding the Abhuinn na Glasa. In the area west of Loch na Glasa the basic material is in the form of round or oval ball-like masses. The colour of the masses being dark, they are strongly contrasted with the pale acid surroundings. The edges are usually very distinct, and the dark masses are permeated with veins of acid material. In some cases these veins form an irregular network traversing the basic material in all directions and cutting it up into angular areas. Many of these exposures show angular masses of the basic material, with very sharp outlines and varying in size from an inch or so up to a foot or more, embedded in the acid granitic material, and often so packed as to give the appearance of an igneous breccia. In field exposures the basic angular fragments weather deep into the rock, but keep a fairly clean face, and the surrounding granitic matrix stands out all round, so that the rock frequently has an appearance as if the basic fragments had been pushed in, and the acid matrix had bulged up between them. Blebs of blue quartz and large felspar crystals occur in some of the masses, which then have a paler colour. According to Dr. Flett, this type is a hornblende granite porphyry, while the true basic types are diorites and in some cases quartz diorites. In the field the frequent marginal position of these types of granite porphyry suggests the absorption of more basic lumps by the surrounding acid magma. This impression is further strengthened by a want of definition of the margins of the associated basic masses, which causes them in places to appear like "ghosts" of the better defined masses seen elsewhere. These angular and ball-like masses of unsheared diorite are embedded in granitic rocks which often macroscopically show

no sign of shearing, and specimens cut and microscopically examined are stated by Dr. Flett to be almost free from the effects of deformation. Where a foliation is present, it appears to have been produced more readily in the acid than the basic material, or at least is more easily detected in the former, as the basic masses frequently retain their angular outlines where the surrounding acid rocks are in a sheared condition. C. B. C.

East of the head of Glen Diebidale, those unfoliated types which have been examined by Dr. Flett are called diorite, augite diorite, augite biotite diorite and epidiorite, but most of the exposures, except near Cnoc na Tuppat, are affected by foliation—either plane-parallel or linear—to a greater or less extent, and may be classed as hornblende schist or hornblende biotite schist.

None of the large basic areas in Diebidale consist of quite unmixed basic rocks, as might be inferred from their representation on the map, being often crossed by granitic veins which are too small to be shown on the one-inch scale. These granitic veins are, as already indicated, usually well defined, though not chilled at their margins, and it is probable that they have been injected into the basic rocks after these latter were consolidated. Apart from the presence or absence of foliation, two main types of basic rock are to be distinguished in the field in Diebidale. One of these is darker and more basic than the other, and is frequently found in the form of small inclusions in a paler type, in which blebs of quartz are generally abundant. The margins of these inclusions are well defined, and it seems probable, therefore, that the darker rock was consolidated before the paler was injected into it. But in other localities, for instance in the crags nearly half a mile south of the Ordnance Station 2250 ft. on Diebidale Ridge, these different varieties are mixed with others in somewhat irregular streaks with ill defined and cloudy margins, and it is suggested that they were at one time flowing together in a semi-liquid condition, and were then partially mixed and changed by chemical reaction between their margins. The part of the crag referred to is almost free from foliation, and the indistinct margins cannot be due to shearing.

Neither in the foliated nor unfoliated diorites are any conspicuous porphyritic constituents as a rule detected. A few exceptional instances may be noticed. The fine-grained unfoliated diorite pierced by the granite in the exposure nearly half a mile east of Leaba Bhaltair, already referred to in the Introduction of this chapter, contains small phenocrysts of felspar about an eighth of an inch in length, and in a hornblende schist two-thirds of a mile slightly east of south of Cnoc na Tuppat felspar phenocrysts attain a length of half an inch. In several exposures of unfoliated diorite south-east of Cnoc na Tuppat a small proportion of the hornblende occurs in phenocrysts about an eighth of an inch in length.

On the north side of one of these diorite exposures, in a position 783 yds. slightly east of north of the Ordnance Station on Carn Dubh, is a peculiar unfoliated rock (10923) which includes many small dioritic patches together with small porphyritic felspars and blebs of quartz, the latter surrounded by aureoles of hornblende. The rock may be called quartz diorite, but is probably a "mixture rock" formed by the union of diorite and a more acid rock.

Garnets have not been noticed either in the foliated or unfoliated types, but macroscopic sphene is tolerably conspicuous in the latter.

C. T. C.

On the west side of Loch na Glasa the basic masses are, as already described, unsheared diorites. On passing northwards towards Beinn Tharsuinn and at the head of Glen Diebidale they become drawn out into long lenticles and strings, and are in the form of biotite hornblende schists, the granite at the same time becoming gneissose. The shearing has been so intense in some places that the acid and basic materials are drawn out into thin parallel bands of gneiss and hornblende schist. Between these intensely sheared rocks and the unaltered rocks west of Loch na Glasa intermediate stages of shearing can be seen, a foliation being frequently developed in the basic masses and in the surrounding acid matrix before any marked deformation of the boundaries of the different materials is apparent. The shearing in this locality appears to have affected the basic and acid rocks simultaneously.

C. B. C.

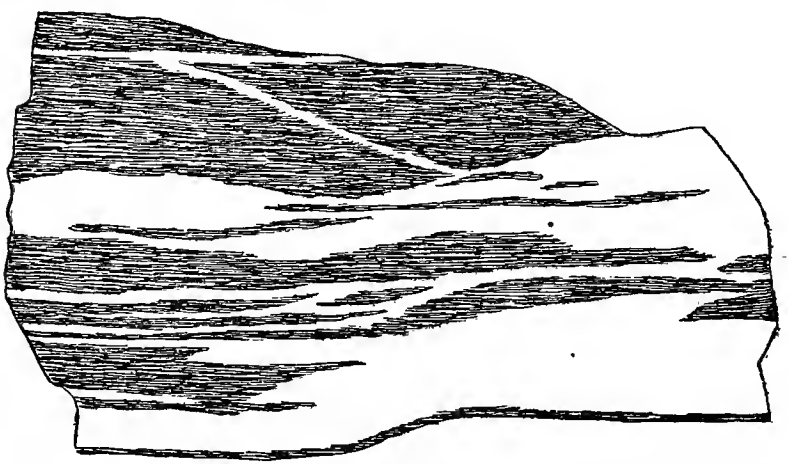


Fig. 4 (× 1).—Surface of a piece of Banded Orthogneiss. 1000 yds. W.N.W. of Leaba Bhaltair. The white streaks are granitic gneiss.

In the various localities further east, for instance in some small streams nearly 1000 yds. W.N.W. of the Ordnance Station on Leaba Bhaltair and in Diebidale River N.N.W. of Creag Illie, we find still more extensive exposures of banded orthogneiss (Fig. 4) composed of thin alternating subparallel streaks and laminæ of pale grey granite gneiss and dark grey hornblende schist, which closely resemble portions of the Lewisian Gneiss of West Sutherland. The thickness of the individual streaks and laminæ is often about half an inch, and, in the streams referred to, the total thickness is probably 100 ft. at least. A linear foliation or rodding in the banded gneiss often crosses the streaks and laminæ, and it is hence suggested that the parallelism of the different portions may be due to the squeezing of veins and tongues which were once of a much more irregular shape. In sections at right angles to the direction of the rodding the pieces of dark grey hornblende schist still often retain markedly angular outlines, and so, if the rock has been much squeezed, it seems necessary to suppose

that the pressures acted in the manner described on p. 49. In parts of a banded gneiss, 10 or 12 ft. thick, which is seen in Diebidale River nearly 1000 yds. south-east of the Ordnance Station 2250 ft. on Diebidale Ridge, the dark parts contain probably as much biotite as hornblende, and the pale and dark parts are arranged in thin parallel planes, not rods, the latter being the disposition in the neighbouring gneiss, in which biotite is scarce. In this case it seems possible that the abundance of biotite may be connected with the greater pressure or shearing to which the rock has been subjected,* but in other localities it does not seem probable that there is any connection between the proportion of biotite and the amount of pressure to which these banded gneisses have been subjected.

In most parts of the Glen Diebidale basic mass the foliation strikes nearly parallel to the long axis of the mass, and the dip is southerly, but in some places it strikes nearly north and south, and is rather sharply twisted. Near Creag Illie the foliation is often vertical and strikes east and west. In the river E.N.E. of Mullach Creag Riaraidh it is sometimes twisted along axial planes striking south-west, and various granitic strings are twisted with it.

The hornblende schists and hornblende biotite schists produced from the gabbros, diorites, etc. (group i.) are sometimes indistinguishable in hand specimens from schists formed from basic dykes (group iv. B.) which cut the plutonic masses, but the former are as a rule coarser-grained. The basic sills in the Moine Series (group iv. A.), however, though distinct petrologically from either of the above named groups of rocks, are sometimes as coarse as any of them.

In the field the foliated gabbros and diorites (group i.) are sometimes cut by small granitic strings, and are thus readily distinguished from the basic rocks of the dykes, with which otherwise they might be confused.

A small exposure about 1020 yds. south-east of the Ordnance Station on Cnoc na Tuppat, and not far inside the plutonic mass, consists chiefly of pieces of hornblende schist, from a yard to a few inches in length, which vary considerably in grain and in direction of rodding, and are mixed with a few pieces of biotite schist and of altered pelitic sediments. The exposure is crossed by many veins of quartz and granite, some as much as six inches thick, which have a general E.N.E. direction, parallel to the long axes of most of the pieces. Possibly this peculiar exposure represents a deeply seated friction breccia which has been veined by granite.

ii. ACID PLUTONIC ROCKS. GRANITE, APLITE, PEGMATITE, FOLIATED AND UNFOLIATED.

Introduction.

The acid plutonic rocks have much the widest distribution. In the Carn Chuinneag mass they occupy probably about thirty times the area of all the other rocks, and in the Inchbae mass they compose an even

* For parallel cases in which biotite takes the place of hornblende in rocks which have been subjected to an unusual amount of shearing, reference may be made to 'The Geological Structure of the North-West Highlands of Scotland,' *Mem. Geol. Survey*, 1907, pp. 140 and 209. See also the subsequent description of group iv. in this chapter.

greater proportion. They are divisible, however, into various types, the most important of which are shown in the following list :—

f. Pegmatites and quartz veins in or very near the plutonic masses. Rare. Foliated in part.
e. Fine-grained muscovite gneiss without much biotite. Probably represents aplite.
d. Fine-grained biotite granite gneiss without many large felspar phenocrysts.
c. Coarse biotite granite or granite gneiss with many large felspar phenocrysts. "Augen gneiss" or "Inchbae rock." A very common type.
b. Dark grey granite gneiss rich in biotite.
a. Riebeckite gneiss.

As already stated (p. 46) the plutonic rocks show a sequence from more basic to more acid types. For example, the dark grey gneiss (*b*), rich in biotite, was apparently the first to consolidate, for in Diebidale River (at a point about 1120 yds. E.S.E. of the Ordnance Station 2250 on Diebidale Ridge) this gneiss is cut sharply by the paler biotite gneiss (*d*), which is elsewhere closely connected with the augen gneiss (*c*) by a series of transitional varieties. The pale muscovite gneiss (*e*) and the pegmatites (*a*), on the other hand, sometimes form strings in the augen gneiss (*c*) and the fine biotite gneiss (*d*). The age of the riebeckite gneiss with reference to the other plutonic rocks has not, however, been ascertained. C. T. C.

In the map under description an attempt has been made to show the main areas occupied by divisions "a" and "c," the others being all grouped together, but the boundaries are not in most places very definite, partly owing to large areas of obscure ground and partly because of the presence of the intermediate types, already referred to, between divisions "c" and "d." It will be seen that the last division, the augen gneiss, is decidedly the most widespread, and occurs all along the margin of the Carn Chuinneag mass except at one locality, about half a mile north-west of Carn an Liath-bhaid. It may therefore be said to have formed originally the lower part of the laccolite *—a position into which it seems not impossible that the felspar phenocrysts may have sunk down from higher portions. The augen gneiss, however, makes a much broader area on the south-east side of the Carn Chuinneag mass than on the north-west, where the earlier basic rocks chiefly occur. Near Lochan a' Chairn the breadth in a north-west direction is as much as three miles. In the Inchbae mass the augen gneiss forms an even larger proportion, but does not occur along the northern margin at Meall nan Sac : it is excellently exposed near Inchbae Lodge, and is hence often called the "Inchbae rock."

These granitic rocks do not usually form high ground, but on Carn Chuinneag they attain a height of 2749 ft., and along the watershed westward they exceed 2000 ft. in three places. The greatest height attained elsewhere is along the margin where they come into contact with the sediments. North of Strathrannoch house they form large expanses of flat or gently undulating country stretching towards Glen Diebidale, and on the whole form lower ground than the surrounding sediments. In the hollows and lower tracts there is an enormous development of peat, and the rocks are bleached and much weathered by the action of the peaty acids. Knobs, either rough and breaking into

* See Introduction to this chapter.

blocks, or polished by ice-action, emerge here and there from the peaty covering, and are also characteristic of some of the higher elevations.

The coarse augen gneiss of Carn Bhren, 2080 ft., and of Carn Sonraichte, 1684 ft., is usually in rounded glaciated forms, though piled blocks frequently give a rough outline. The blocks formed by the breaking up of this coarse type are sometimes very great, and equally large blocks characterised the weathering in or before the Old Red Sandstone period (see Chapter VIII.), and in glacial or preglacial times (see Chapter X.).

The riebeckite gneiss, a somewhat fine-grained rock, forms the top of Carn Chuinneag, and other fine-grained granite rocks form the northern, southern and western slopes of this hill, but are chiefly represented by screes, composed of blocks from 2 to 6 ft. long.

In all the acid plutonic rocks, a distinct foliation, either plane-parallel or linear, is usually present. In those with linear foliation it is not always easy to determine the dip of the rods, but in the Carn Chuinneag mass the general dip, both of rods and foliation planes, appears to be south-east, at high angles, often between 40° and 60°.

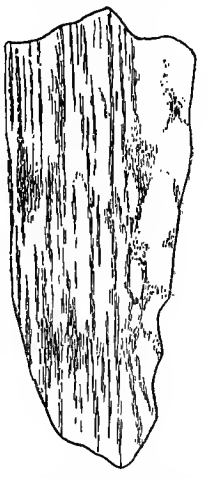


Fig. 5 (×1).—Piece of Granitic Gneiss partly Re-sheared. Near a thrust in Garbh Allt, 950 yds. south-east of the foot of Alltan Sgeireach. The left-hand side is close to the thrust.

Occasionally two foliations can be seen, a first and a second, the latter crossing the former or else merging with, and greatly modifying it. It is believed that the first or main foliation was produced after consolidation, and that it can be matched with a foliation produced contemporaneously in the Moine sediments. The chief reasons for this belief are summarized below :—

1. Where the granite is in contact with unsheared Moine hornfels it is free from foliation. Where it is well foliated, the adjacent Moine rocks are highly sheared.
2. The foliation frequently crosses the margins of the granite and passes thence into the sediments.
3. The foliation—the only one locally observed—often crosses from one igneous rock into another. An original flow structure would not do so.
4. Petrological examination shows that in the porphyritic granites the phenocrysts of quartz and felspar are usually less sheared than the matrix, which must consequently have been solid before the rock was crushed (see Dr. Flett's description in Chapter VI.).

Dr. Peach was the first to notice that the margins of the augen gneiss were crossed by the foliation planes, which were apparently continuous with those in the adjacent Moine schists : this he observed on the north side of Loch Luichart.* A good case of the same kind also occurs at Meall nan Sac, at the north end of the Inchbae plutonic mass, where the foliation in a fine-grained granite gneiss dips E.S.E., and strikes almost at right angles to the margin, but in much the same direction as that in the Moine rocks. At the south end of the Inchbae

* *Summary of Progress of the Geological Survey* for 1898, p. 9.

mass, also, the foliation dips nearly east, and strikes parallel to the long axes of various granitic projections that are probably due to folding. Again, at Carn an Liath-bhaid, at the north-east end of the Carn Chuinneag plutonic mass, the direction of the main granite margin is nearly north-west, but the foliation often strikes north-east.

Various places, where the foliation crosses the boundaries between different igneous rocks, have been already mentioned (pp. 49, 52). Near Cnoc na Tuppat, an unusually interesting exposure (p. 63 and Fig. 9), shows foliation planes crossing from a quartz vein into pegmatite, and from pegmatite into granite gneiss; we suppose that the granite was solid at the time the quartz vein was formed, and that it still remained so at the later period when the foliation was produced. Some of the thin sharply defined aplite veins in the augen gneiss of Carn Salochaidh provide evidence of a very similar character.

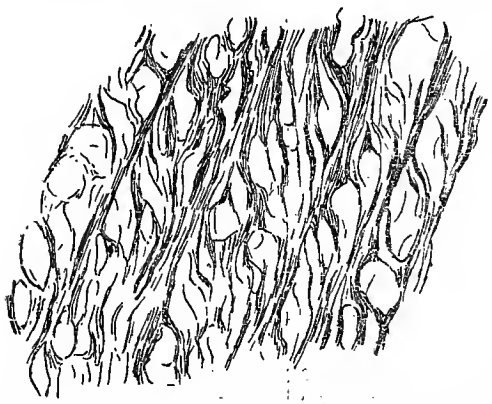


Fig. 6 (× 1).—Augen Gneiss with strain-slips. West side of thrust in Garbh Allt, about 960 yds. south-east of the foot of Alltan Sgeireach.

The second foliation is usually finer than the first. It may entirely hide it, and in various places it is doubtful whether we are dealing with a first or a second foliation.

The N.N.W. thrusts in Garbh Allt (Fig. 10), near which the sedimentary rocks are highly sheared, as described in Chapter V., affect the granitic sills also. It is found in many places that where these sills dip gently in a direction slightly east of south they show linear foliation or but slight indications of plane-parallel foliation, but near the thrusts they twist suddenly into a N.N.W. strike, and become vertical or bent into close folds with vertical axial planes striking N.N.W. At the same time they become thoroughly granulitic, and are dragged out into thin vertical folia approximately parallel to the thrust. At the side of a thrust which crosses the Garbh Allt about 950 ft. south-east of the foot of Alltan Sgeireach, the whole of the granitic rock is granulitic, but the part nearest the thrust is also closely foliated into parallel planes (Fig. 5), and shows in these planes numerous scales both of black and white mica, the latter probably formed from the shearing of felspar, as it is not usually common in the granite away from the thrust.

The granitic rock close to another N.N.W. thrust, some 10 or 15 yds. east of that just referred to, was originally probably of a more porphyritic character, and many of the old felspar phenocrysts are represented by small red augen which still show broad cleavage faces crossing from side to side. These augen are often surrounded by streaks of white quartz in a finely granulitic condition. The rock has a special interest, because it shows not only a first foliation, along

which the long axes of the augen lie, but also some indications of a second or strain-slip foliation, which has been formed from the first by folding and strain-slipping along the thinned limbs of fold.

At the mountain pass about half a mile north-west of the top of Carn Salochaidh the junction of the Moine rocks and the main mass of granite strikes about north-east, and both rocks are sheared in an unusually high degree along a line of thrust or special movement keeping near the junction. Just on the north-west side of the pass the Moine rocks are mixed with thin veins of granite, and both are closely folded along axial planes striking north-east, and are crossed by a foliation parallel to these axial planes. The granite still shows small felspar augen, but contains also, in the foliation planes, many flakes of white mica which have probably been formed by the destruction of part of the original felspar. Still more flaggy and schistose, and richer in white mica, are some of the exposures of sheared granite on the south-east side of the supposed thrust nearly a quarter of a mile south-west of the pass.

Fig. 7 (× 1).—Granitic Gneiss between 5 and 7 ins. off a Dyke of Hornblende Schist. A third of a mile slightly west of north of Leaba Bhaltair. The right-hand portion of the specimen is nearest the dyke, and its foliation planes are parallel to the side of the dyke. In the central portion two sets of foliation planes are visible; one making rather broad laminæ is earlier than the other; these broad laminæ are sometimes faulted along planes of movement belonging to the later foliation.

At the sides of many of the basic dykes of group iv., to be subsequently described, the granitic rocks are very finely foliated, parallel to the dyke side and the foliation in the dykes. These granitic rocks must have been in a solidified state at the time of the intrusion of the dykes, and the foliation in them close to the dykes was also doubtless produced, or greatly modified, subsequently to this intrusion, at the time of the production of the foliation in the dykes. In the granitic rock, about eight inches off the side of one of these dykes, somewhat broader foliation planes are observed which make a perceptible angle with the dyke side, and are like those which are often found still further off the dykes. On close examination it is seen that these broad planes are crossed by various lines of fault or shear (Fig. 7), sometimes accompanied by crumpling, which are parallel to the dyke side and to the finer foliation in the granite. The existence of these shear-lines makes it seem very probable that the granite was already coarsely foliated throughout before the finer foliation near the dyke was developed.

C. T. C., C. B. C., E. M. A.

a. *Riebeckite gneiss.*

A considerable band of this rock extends nearly north and south across and east of the summit of Carn Chuinneag, though very little is actually exposed. The total length of the band is probably about a mile and a quarter. The best exposure is perhaps on Meall Eadar an da Chuinneag. Another smaller band occurs on the low watershed west of Carn Chuinneag, but this also is chiefly represented by loose blocks, and but poorly defined.

The rock is readily distinguished from any other in the complex by its needles of intensely black hornblende, which might at first sight be mistaken for tourmaline, and often occur in groups forming little rods a quarter or half an inch long. Apart from these the colour is pale grey, sometimes with redder areas, and both felspar and quartz are granulitic, without any admixture of phenocrysts. The neighbouring gneisses are rather fine-grained granitic gneisses, of division "d," but no junction with them is anywhere seen. No strings of any other type of rock have been anywhere seen within the riebeckite gneiss, but granulitic quartz veins with riebeckite in unusually large forms, sometimes more than an inch long, are not uncommon. The foliation both in the riebeckite gneiss and the neighbouring gneisses is chiefly of the linear or rodded type, and at and near the summit of Carn Chuinneag the direction of rodding is nearly south-east, at 40° or 50°—much the same as that usually seen in the neighbouring gneisses. Just on the west side of the summit of the hill, the rock west of the riebeckite gneiss is intensely sheared into thin flags, containing abundant white mica as well as black, which might be taken for semipsammitic Moine schists. It seems probable, therefore, that the western boundary is a thrust or line of special movement.

Chemical analyses and full description of the petrological characters are given in Chapter VI. C. T. C., C. B. C.

b. *Dark grey granite gneiss rich in biotite.*

This division is a small one, and is not separated on the one-inch map. It forms various patches which are intimately mixed with and sometimes seen to cut the dioritic rocks in Diebidale River north and north-east of Creag Illie. These patches are, in turn, cut sharply by pinker veins of more acid granite, which contain much less biotite. One of the patches contains thin strings of some carbonate which suggests that the original unsheared rock may have contained hornblende.* A coarse biotite schist containing specks of carbonate occurs also within the granitic gneiss, and seems to pass gradually into it, in the burn nearly a mile north-west of the summit of Carn Chuinneag.

Some bands of dark grey biotite gneiss are found in the dioritic crag on the north-west side of the river north-west of Creag Illie, and one of these contains a small proportion of hornblende as well as biotite: another band contains small garnets and intensely crumpled thin quartz veins.

A coarse-grained rock containing big pieces of quartz and felspar, with much biotite and grains of carbonate, forms a thin band striking north-west, about 350 yds. somewhat west of north of the Ordnance Station 2175 on Creag Ruadh. It seems to cross the foliation of the

* Reference may be made to the description of group iv.

redder gneiss at its side, but is not sharply separated from it, and may be a vein-like modification. Dr. Flett states that the felspathic constituents comprise orthoclase, oligoclase and albite (13967). Some of the felspars have been of large size, but much crushing has taken place, accompanied by the development of mortar structure.

In the Inchbae augen gneiss a few thin seams of dark biotite gneiss, only a few inches thick, in Allt an Eilean Ghuirm, may possibly belong to this division. One of these is seen about a quarter of a mile above the foot of the burn.

c. *Coarse biotite granite or granite gneiss with many large felspar phenocrysts—Augen gneiss or Inchbae rock.*

This forms the marginal rock all round the Carn Chuinneag plutonic mass except for a small space about half a mile north-east of Carn an Liath-bhaid. It also appears to form nearly the whole of the Inchbae mass except the northern margin, and occupies, no doubt, a considerably larger area than all the other divisions of group ii. taken together. The limits are, however, by no means sharply defined, there being insensible gradations along two paths from the coarse augen gneiss into the finer granitic types of division "d." On the one hand, the felspar phenocrysts may become gradually rarer though still retaining a large size individually. On the other hand, they may keep up or increase their numbers but become so small that they cease to attract much attention. Intermediate types showing large but rare phenocrysts are well seen a little north-east of Lochan a' Chairn and also between Carn Salochaidh and Carn an Liath-bhaid. A section about three-quarters of a mile west of Carn an Liath-bhaid shows several parallel bands, most of them several yards wide, which contain felspar phenocrysts, from half an inch to an inch in length, in very varying abundance. These bands all show foliation in much the same degree, and those in which the phenocrysts are rare do not appear to be more sheared than the others : it seems quite possible that these different types may have been flowing together in parallel bands before consolidation set in. In another section rather more than three-quarters of a mile E.N.E. of the outlet of Lochan a' Chairn somewhat similar parallel bands are again exposed, but in this there is the additional point of interest that the foliation crosses the margins of the bands.

It seems possible, nevertheless, that in certain localities the fineness of grain may be due to more intense shearing. In a section mainly composed of augen gneiss, nearly a mile north-east of the foot of Lochan a' Chairn, a four-inch vein without porphyritic felspars is displaced 18 in. along a thinner somewhat similar vein which is foliated parallel to its own side. Parallel to this line of movement, and a few feet off, is another ten-inch vein which contains a number of felspar augen, but most of these are less than half an inch long, while many of those in the rock at its sides are as much as an inch. On closely examining the margins of the ten-inch vein, individual streaks of quartz can be traced from the one rock into the other, and where they enter the vein they are seen to be thinned and dragged almost into parallelism with its side. The granitic rocks at the south-west end of the Carn Chuinneag plutonic mass generally consist of coarse augen gneiss with somewhat obscure foliation. But in one locality, rather more than

a quarter of a mile slightly east of south of the summit of Carn nan Aighean, the rock is sheared out so as to resemble a mica schist with isolated "eyes" of felspar: the direction of shearing is approximately parallel to the adjacent margin of the granite. It is also noticed in the Inchbae mass, that in the most thinned limbs and near the strain-slips of certain folded portions, to be shortly referred to, the felspar augen are decidedly less conspicuous than in the general mass of the rock, while quartz and biotite seem in increased proportion.

Granitic rocks, which may be regarded as almost unsheared representatives of the augen gneiss, are found in the following localities: close to the margin of the granite 1000 yds. slightly north of east of the Ordnance Station 2250 on Diebidale Ridge; about 20 yds. within the margin of the complex nearly half a mile north-east of Carn an Liath-bhaid; 1800 yds. south-east of Beinn a' Chaisteil; on Carn Cas nan Gabbar; and a little to the west of Loch na Glasa. But in none of these places except the last do the felspar phenocrysts attain the dimensions occasionally reached in the augen gneiss. West of Loch na Glasa the most conspicuous variety of granite is a coarse biotite granite, or granite porphyry, with large felspar phenocrysts showing Carlsbad twinning. Microscopic examination shows that some of the exposures are almost free from alteration, though others are considerably deformed and granulitised. In this locality, too, there is sometimes, next to the earlier basic masses belonging to group i., an unusual type of rock which has not been indicated in the list given on p. 54. This rock is a hornblende granite porphyry, which, as already stated in the description of group i. (p. 50), seems a mixture rock, which has been formed by the absorption of basic material by the invading acid magma. Some irregular granitic strings in Garbh Allt (Fig. 10), 880 yds. S.S.E. of the foot of Alltan Sgeireach, contain felspars more than half an inch long, and numbers of bluish opalescent quartz blebs about the size of peas, which show original zones of growth, not very much deformed. Some of the felspars in the first locality mentioned, near Diebidale Ridge, are three-quarters of an inch long, and are almost water-clear though the smaller felspars are reddish. In the second locality the larger felspars are slightly more than an inch long, nearly white, and associated with blebs of bluish opalescent quartz, like those mentioned in the Garbh Allt. In one place, about 917 yds. from the Ordnance Station on Carn an Liath-bhaid, this rock is crossed by a thin shear-zone, striking nearly east and west, in which the quartz blebs lose their bluish colour and become drawn out into long granulitic streaks. At the same time the larger felspars lose their crystalline outlines, become granulitic at the edges and assume the form of augen. Near the margin of the granite a little east of Carn Bhren a very handsome variety of gneiss contains felspar augen sparsely scattered through a granulitic matrix, which is partly made up of long streaks or rods of granulitic quartz, whiter and clearer than the rest: it is evident that these streaks represent deformed quartz blebs like those already referred to. Near Carn Bhren the streaks of quartz are not very abundant, but in certain localities the quartz is in much greater proportion, and forms long continuous streaks winding round the felspar augen: we suppose that the original rock in these cases was unusually rich in quartz blebs, but perhaps not richer than some of the granitic strings in the Garbh Allt.

The felspar phenocrysts, as already indicated, are generally of an almost white or pale pink colour, and in their central portions still often show cleavage planes and Carlsbad twinning. In the section in the lower part of Strath Rannoch Burn, near Inchbae, the augen are often two inches long and half or three-quarters of an inch broad. Only small portions near the centre usually remain ungranulitised. Quartz streaks, entirely granulitic, and flakes of biotite form sheaths winding round the augen. No white mica appears to occur. About a quarter of a mile above the bridge the first or broad foliation is folded along an axial plane inclining east (Fig. 8), and in other places higher up the stream it is again folded, along axial planes inclining east or south-east, and is crossed by strain-slips, as already stated.

In parts of the Carn Chuinneag plutonic mass the felspar augen are just as large as at Inchbae. In an exposure between 240 yds. S.S.W. and 700 yds. slightly south of east of the summit of Carn Dubh, some of the augen are more than two inches long and an inch

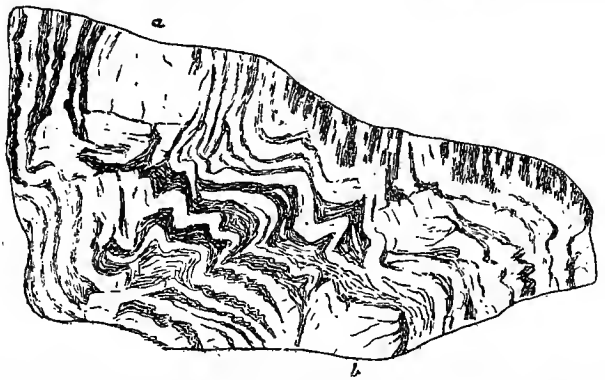


Fig. 8 (× 1).—Augen Gneiss with Twisted Foliation. From a block, probably nearly *in situ*, in Strath Rannoch Burn a quarter of a mile above Inchbae Bridge. Deformed felspar phenocrysts are seen just below "a" and above "b."

broad, and contain considerable inclusions: some of the augen are almost free from granulitisation and are nearly white, but others are largely granulitic and pinkish. A number of those which are the least granulitised are nevertheless crossed by thin granulitic streaks. The matrix varies considerably in proportion to the augen and in its own character. Rather exceptionally it consists chiefly of granulitic quartz which forms streaks winding round the augen and projecting beyond them in the weathered face. In other localities the matrix is softer and pinker, and probably contains more felspar than quartz. On the south side of the exposure comes a band in which the augen are sparse but often about an inch long.

d. *Fine-grained biotite granite gneiss without many large felspar phenocrysts.*

Hornblende has been observed macroscopically in association with the biotite in one locality only, in a thin string which cuts the augen gneiss in the tributary burn flowing west nearly a mile S.S.E. of Cnoc nan Sac. In the common types biotite is abundant in small

flakes. White mica may also occur, even in samples which do not seem unusually sheared, for instance on Carn Dubh. The rocks of this group, on the north side of the boundary line indicated in the map, contain numerous small specks of granulitic felspar, generally less than a quarter of an inch in length, and sometimes surpassed in size by other specks of granulitic quartz. The boundary line between these rocks and the augen gneiss on their south side seems tolerably definite, but no actual junction is exposed.

Further east, in the burn about a mile below Lochan a' Chairn, a fine biotite gneiss, with felspars about a quarter of an inch long, is seen just north of an augen gneiss with felspars often an inch long. There is no clear indication that either rock is intrusive into the other.

About half a mile north-east of the summit of Carn Chuinneag the boundary between the augen gneiss on the north-east and a finer gneiss with felspars about $\frac{1}{8}$ in. long appears to coincide with the base of a steep bank, facing north-east, which may perhaps represent a fault.

On the western slope of Carn Chuinneag most of the rock is evidently of a fine-grained type, though it is chiefly represented by screes of loose blocks. Most of it is characterised by linear rather than plane-parallel foliation, and it contains a good number of dark grey schistose lenticular streaks, rarely more than a foot long, which are very rich in biotite and contain occasional small white felspars.

Good exposures of fine-grained gneisses with linear foliation are seen on the north side of Leaba Bhaltair and east of Creag Illie. In the latter locality, in a position 630 yds. N.N.W. of the Ordnance Station 2174, is a thin pale grey band of an unusual type which contains garnets, and rather more white mica than black. Perhaps some of the white mica has been developed by shearing from felspar. The locality is nearly 700 yds. from the margin of the plutonic complex.

Some of the fine-grained granitic strings which go through the augen gneiss are rich in biotite, and do not appear to differ from the larger masses belonging to the division being described, except that they are, perhaps, still finer-grained. The little string which contains both hornblende and biotite, in the tributary burn nearly a mile S.S.E. of Cnoc nan Sac, is foliated vertically parallel to its side, though the foliation of the adjacent augen gneiss is lying at gentle angles. The string must, therefore, have formed a line of weakness along which shearing has proceeded. C. T. C., C. B. C., E. M. A.

e. *Fine-grained muscovite gneiss without much biotite.*

This rock never makes large masses, and is chiefly in the form of thin strings within the coarser gneisses. It probably represents aplite for the most part. The general colour is pink. Perhaps the largest exposures are in the burn which runs westward into Diebidale River near the Lodge. The lowest exposure, about 400 yds. slightly south of east of the Lodge, is about 30 yds. wide, and lies between a big mass of hornblende biotite schist, belonging to group i., on the west, and a thin band, perhaps 6 or 7 yds. wide, of a biotite granite gneiss, belonging to division "d." Beyond this thin band, fine-grained muscovite gneisses are again exposed, but in smaller patches mixed with other rocks.

A nine-inch pale cream or pink string, with hardly any biotite, occurs in a N.N.W. shear zone in the Garbh Allt (Fig. 5), 967 yds. south-east of the foot of Alltan Sgeireach. It is in contact with augen gneiss on one side and sheared Moine rocks on the other.

Examples of fine-grained sheared strings, which are almost free from biotite, are seen in the augen gneiss 700 yds. south-east of Cnoc an Liath-bhaid and three-quarters of a mile north-east of the foot of Lochan a' Chairn. In the former locality some of the strings are about a foot thick, vertical and foliated, parallel to their side, much more intensely than the adjacent gneiss. They must have formed lines of weakness along which the later shearing movements have proceeded.

f. *Pegmatites and quartz veins in or very near the plutonic masses.*

Very few pegmatites with much felspar have been observed in or near the plutonic rocks, and none of those so found has been traced more than a few yards. Big pegmatites occur in certain of the Moine rocks far away from the plutonic areas, but these have never been seen in a sheared condition in this map, and they appear to have been introduced since all the schist-making movements near them had ceased.* The few pegmatites exposed in or close to the plutonic masses are, on the other hand, granulitised and sheared to a considerable extent, and have probably been subjected to the same movements as the other plutonic rocks near them, though in consequence of their coarse grain they have perhaps not so readily yielded to the movements.

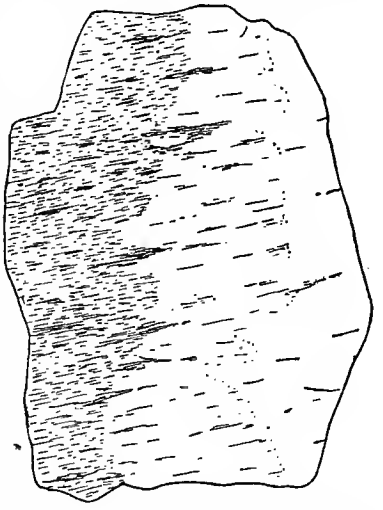


Fig. 9 (× 1).—Specimen showing fine-grained Granitic Gneiss on left, Pegmatite in centre, Quartz Vein on right. The two first-named rocks are crossed by many foliation planes that are common to both. The quartz vein shows a few foliation planes that also continue into the pegmatite. Nearly a mile and a quarter slightly north of east of Cnoc na Tuppat.

Several pegmatite veins, from one to four inches thick, occur in the granite gneiss and altered sediments about a mile and 340 yds. slightly north of east of the summit of Cnoc na Tuppat. They consist chiefly of felspar and quartz, the former sometimes in pieces more than two inches long, which are divided into smaller island-like portions of bluish grey ungranulitised felspar by reddish granulitic strings: many of the contiguous island-like portions show parallel cleavage planes and have evidently belonged originally to one large crystal. Biotite is rare or absent, but white mica is abundant in certain parallel foliation planes which continue into the adjoining gneiss or schist, and also occasionally into quartz veins (Fig. 9).

* These pegmatites are described in Chapter II., in the descriptions of the different districts in which they occur.

About a third of a mile W.S.W. of the Ordnance Station 1347 on Carn Dubh several thin pegmatites, less than an inch thick, keep along the foliation of the fine-grained granite gneiss, and are themselves in a somewhat granulitic condition.

A thin pegmatite in the "stippled schists" * of the Moine Series, a mile and 666 yds. west of Carn Bhren, is almost free from granulitisation. The felspar is pale pink or white, and the quartz bluish, like the quartz blebs in some of the less sheared granitic rocks.

Along the junction of the granite gneiss and Moine schists at the north end of the Inchbae plutonic mass, at Meall nan Sac, pegmatites are seen in several places, and loose blocks of pegmatite are also common in the drift-covered ground a little further east. Some of the bands indicated must be at least two or three feet wide and contain quartz veins six inches wide. All these pegmatites are reddish, and have perhaps been covered by the Old Red Sandstone not very long ago. Their felspar is to a large extent granulitic, but still shows ungranulitised augen, as large as a hen's egg, in which microperthite structure can be detected.

Judging from the numerous loose pieces of vein-quartz near the top of Carn Chuinneag and on the west side of Loch Chuinneag, veins consisting chiefly of quartz but with occasional specks of felspar must be rather abundant in these localities; but they can rarely exceed six inches in breadth.

Many of these loose pieces are semi-translucent and somewhat brown or "smoky" like "Cairngorms," in most of their substance,† but they are frequently crossed by opaque white streaks of a somewhat granulitic character. Veins with similar granulitic streaks are seen *in situ* in the granite gneiss in the south-east bank of the stream nearly half a mile E.S.E. of Meall Eadar an da Chuinneag.

In certain places crystals of translucent white, pink or smoky quartz are also not uncommon, lying loose on or below the surface of the ground. They are sometimes attached to quartz veins and have evidently grown out into cavities which existed either at the side or in the interiors of such veins. Small pieces of chlorite and specular iron are also occasionally found in association with them. In some specimens well formed quartz crystals, perfectly free from deformation, are attached to one side of a quartz vein, while the other side is welded on to a rodded granulitic gneiss in which the rods are pointed almost at right angles to this side. It seems necessary to conclude in these cases that the crystals have been formed after the rodded granulitic structure. C. T. C., C. B. C.

iii. GARNETIFEROUS ALBITE GNEISS WITH MAGNETITE AND TINSTONE.

In the rather fine-grained reddish granite gneiss about half a mile south of Diebidale Lodge (Fig. 16), several dark gneissose bands are observed which weather in round blocks and disintegrate readily into

* See Chapter V.

† These are referred to in the 'New Statistical Account of Scotland,' 1845, p. 409. Whether the writer of the passage knew that the adjoining rocks consisted of granite is not clear.

a brownish soil. They can also be distinguished in the field by the following characters :—

1. The great abundance and size of the biotite flakes.
2. The presence of garnet, sometimes in round lumps an inch or two in diameter.
3. The abundance of white plagioclase, determined by Dr. Flett to be albite.
4. The carious mode of weathering, due to the presence of scattered grains of some carbonate.
5. The presence of strings of heavy black ore.

The strings of black ore mentioned above have been found on chemical examination to consist chiefly of magnetite mixed with variable proportions, sometimes as much as 15 or 17 per cent., of cassiterite. Biotite is not uncommon within the strings, in flakes lying parallel to the sides.

It seems probable, on the whole, that these garnetiferous albite gneisses represent basic segregations of an unusual type, or else peculiar veinstones formed in the granite gneiss.

Two main bands of this grey albite gneiss have been mapped. The crop of the more northern one runs north-east, and has been traced about 250 yds., while the crop of a higher second band, 70 or 100 yds. south-east of the other, has been followed in an E.N.E. direction for 100 yds. (see Fig. 16). The foliation in the adjacent red granite gneiss is not always distinct, but it appears to be approximately parallel to the bands. The northern band is as much as 15 yds. wide in places, and contains more garnet than the southern band but a less proportion of the black ore. In the southern band, the greatest thickness of which is 10 yds., the strings of ore are occasionally three inches thick. Between these two main bands comes another thinner one which also contains streaks of black ore.

It is possible that both the main bands continue considerably further than they have been traced, for the hill surface is to a large extent obscured by drift and loose blocks, both in the north-east and south-west directions. A small exposure of somewhat similar rock is seen on the west side of the forest path about half a mile slightly east of south of the Lodge, but we cannot be sure to which band it belongs. About 200 yds. south of the southern band a number of pieces of the black ore have been found, and some of these are as large as any observed *in situ*. It is certain, from our knowledge of the drift "carry" in the neighbourhood, that these pieces cannot have been derived from any of the exposures described, and it is probable that they have been carried from bands, now hidden under drift, which lie to the south or south-west.

These grey gneisses show a coarse-foliated structure and seem to pass gradually into the red gneiss, usually through an intermediate zone about a yard wide. The neighbouring red gneiss a little distance off the grey bands occasionally shows dark magnetite laminæ and also garnets as large as beans.

The black ore in the grey gneiss is very irregularly distributed, but most commonly it occurs in lenses and streaks which lie nearly along the foliation. Magnetite occurs also, however, intergrown with garnet and in small octahedra within felspar. The margins of the black lenses and streaks are generally slickensided, but in the middle

band the marginal parts of the streaks interlock with felspar, and are bordered by a fringe of scattered grains of black ore.

The south-east (higher) band is crossed by a thin dyke, now composed of calcareous biotite schist. The dyke is not crossed by any black ore streaks, though such streaks occur near its side and strike at it.

It is clear from the slickensided surfaces of the ore streaks that the bands have undergone considerable movement, and with this movement may perhaps also be connected the frequently rounded form both of the garnet and of the felspar, even though, as Dr. Flett states, the latter is almost free from granulitisation. In this comparative freedom from granulitisation these grey bands offer a great contrast to the red gneisses in which they occur. It seems necessary to suppose that the albites of the grey bands have been formed after the granulitisation of the red gneisses was practically completed, but that subsequently the grey bands formed lines of weakness along which renewed movements took place, though not with sufficient intensity to produce much granulitisation.

The locality in which these grey gneisses are seen is probably about 200 yds. east of the nearest sediments, which are of a pelitic or semipelitic type, but it is separated from these by a powerful fault, a supposed wrench-fault, described in Chapter IX., which appears to shift the beds on its east side away to the north for about a mile. Before the fault took place, the grey gneiss bands that are exposed were probably a mile distant from the margin of the plutonic rocks, and the bands inferred to exist under the drift must have been still more distant. No other rocks which can be regarded as sedimentary inclusions occur so far within this margin.

No rock containing tourmaline, the mineral commonly found in association with the Cornish veins of tinstone, has been observed in the one-inch map being described, except near Loch Misirich, on the east side of Ben Wyvis (see Chapter II.), and again near the south end of the Newer (Fearn) Granite (see Chapter VII.). Both these localities are nearly ten miles from the Diebidale bands which yield cassiterite. Fluor spar has only been detected in one locality in this one-inch map: this is in the biotite granite gneiss, about $\frac{5}{8}$ mile east by north of Leaba Bhaltair, and rather more than a mile south of the tinstone-bearing rocks.

The occurrence of albite in albite schists of the Moine series is by no means uncommon (see Chapter II.), and this fact may give the impression that the cassiterite-bearing bands, all of which contain much albite, probably represent altered sediments caught up in the granitic magma. It should, however, be pointed out that a coarse-grained albite-bearing seam (13967) has been noted within the granitic area near Creag Ruadh, Diebidale, and that this seam, though not sharply separated from the more normal granitic rock at its sides, appears to cross the foliation of the rock. The impression conveyed is that it may represent a vein partly formed from the adjoining rock by modification along a line of strain. It contains a considerable proportion of ferriferous carbonate.* Veins containing quartz, albite, chlorite and ferriferous carbonate are, as is well known, of common occurrence both

* For further description reference may be made to the section treating of the dark grey granite gneisses specially rich in biotite, in Chapter IV.

in the Moine schists and in the Dalradian schists of the South-West Highlands.

L. L. Fermor has recently described* a cassiterite granulite from Chappatand, the Hazaribagh district, Bengal, which has some points of resemblance to the Diebidale cassiterite-bearing rocks. The Chappatand rock sometimes contains as much as 50 per cent. of cassiterite, the other constituents being magnetite, quartz, oligoclase, orthoclase, in small quantities, green hornblende in small quantity, and biotite in still smaller quantity.

Further petrological and chemical description, and speculations on the mode of origin of the Diebidale bands, are given in Chapter VI. by Dr. Flett.

iv. BASIC DYKES AND SILLS.

These are generally in the form of epidiorite, hornblende schist, hornblende biotite schist, or chlorite schist. As already stated near the beginning of the chapter, they are conveniently divided into two geographical divisions, viz. :—

A. Intrusions in the Moine Rocks.
B. Intrusions in the Plutonic Masses.

Each of these divisions perhaps contains intrusions of more than one period. It is also possible that some of the intrusions described here may belong in reality to sheared types of the Newer Igneous rocks, but it does not seem probable that the bands which may thus have been wrongly placed are numerous.

In the following description we shall include in group iv. all those minor intrusions which are well foliated, excepting certain schists which have marked chemical and petrological affinities with the lamprophyres, or which we have strong grounds for supposing have been intruded into the Moine rocks after these had already acquired a foliated character.

A. *Intrusions in the Moine Rocks.*

Though neither large nor numerous, the rocks to be described are well represented in some form or other in nearly all parts of the map.

C. T. C.

Garnet amphibolites and epidiorites are associated with the muscovite biotite gneiss crossing Strath Rusdale and Ben Wyvis, and also with the quartzose series lying to the east of this band, and they are most frequently met with near the junction of these two sets of rocks. They may be observed on Cnoc a' Mhadaidh and Cnoc an t-Sithein Mor, north of Strath Rusdale, but appear to be most strongly developed in the crags on the west side of Loch Morie, where, from a band of unusually great thickness, big blocks of the garnet amphibolite have been dislodged, and lie at the base mingled with other large blocks of muscovite biotite gneiss. Rocks of this type have not been observed along the crop of muscovite biotite gneiss between Aultguish and Coire Mor, and it is possible that the gneiss along this western anticlinal fold has not been sufficiently deeply eroded to reach

* *Records of the Geological Survey of India*, 1906, vol. xxxiii. Part 3.

the horizon of these bands. Specimens from the northern shore of Loch Glass, opposite Culzie Lodge, examined by Dr. Flett, are reported by him as zoisite amphibolite (9860) and epidote amphibolite (9863, 9864). These were from rocks which differed materially to the naked eye from the more typical ones, but were closely associated with the latter.

The garnet amphibolites occur as lenticular bands and masses along the strike of the schists. They vary in size from small lenticles, one foot across, to broad bands many yards in width, the rocks in the latter being massive in character. They consist chiefly of black hornblende with numerous red garnets, and often show little foliation towards the centre. The margins are, however, foliated and are chiefly composed of black biotite in large flakes wrapping round masses of broken garnet, often of large size. In many places the bands are foliated throughout and often contain a little felspar. Owing to the intensity of foliation no evidence of the intrusive nature of these rocks was observed in this district. C. B. C.

In the north-western portion of the map various bands of hornblende schist are well seen in the crags of Cail Mhor on the north side of Gleann Beag, where they usually make narrow nicks and show their intrusive character clearly, being in the form of dykes or sheets which are more steeply inclined than either the bedding or foliation of the Moine rocks. On the south side of Bodach Mor a band running north-east makes a gently inclined greenish ledge, which has been traced more than half a mile and cuts the bedding of the Moine rocks at a slight angle, getting into apparently higher beds in a north-easterly direction. In Glencalvie Water, about a quarter of a mile and again nearly a mile above the foot, various thin bands behave as sills for the most part, and the sill-like mode of occurrence is perhaps the most common in the district generally, though no band is usually traced far without affording satisfactory evidence of its intrusive character.

Nearly all these bands have a decidedly basic composition, and consist of well foliated hornblende schist, hornblende biotite schist, biotite schist or chlorite schist. In some cases where the evidence of intrusion is clear the foliation is parallel to the sides of the intrusion, but in others it crosses the sides and is continuous with the prominent foliation in the Moine rocks. In the former cases the foliation differs from the prominent foliation in the Moine rocks, and, as far as recognised, is unaccompanied by any corresponding secondary structure in them. The first presumption regarding such cases is that the bands were intruded into the Moine rocks after these last had already been converted into schists, and that the bands have been converted into schists by later movements confined to themselves. But this is perhaps not a safe conclusion. It is possible that some of the bands may have been at one time crossed by a foliation in much the same direction as that in the Moine rocks, but that the foliation in these intrusions has been subsequently greatly modified and dragged out of its original direction so as to be practically parallel to the side.

Bands which cross the bedding of the Moine rocks, and which also show the same foliation as these rocks, have not been very often observed, but examples are seen in Glencalvie Water about three-quarters of a mile south-west of Cnoc na Tuppat, and also on the north side of Gleann Mor about two miles north-east of Deanich Lodge. In

a sill in the burn a mile and a quarter north-west of Deanich Lodge the foliation crosses the margin and is continuous with that in the Moine rocks, but it is not known that there is any clear evidence of intrusion.

Indications of felspar phenocrysts are not common in these schists, but some as much as half an inch long occur in tolerable abundance in large blocks of hornblende biotite schist lying at the foot of the north end of Meall na Rainich, Gleann Mor. The blocks have probably slipped from a band some distance up the hillside, but they could not be traced confidently to their source. In some of the blocks the phenocrysts are in places so abundant that they make up a quarter of the surface, for an extent perhaps of half a square foot. Some are granulitic, but others show broad cleavage planes across their whole breadth.

Garnets are abundant in some bands, *e.g.*, in those near the north end of Loch Coire Mhic-mhathoin (10382), a third of a mile north-east of Glenbeg house (10380) and nearly a mile north-west of Deanich Lodge. In the first mentioned band it forms, in conjunction with felspar, small spots the size of peas, which are frequently edged with thin rims of white felspar * and are accompanied with other spots, of about the same size, which consist of granular aggregates of felspar and quartz with a little hornblende. One or two bands, for instance, a green schist in the burn nearly half a mile north-east of Cnoc na Tuppat, contain small spots of quartz, which are suggestive of amygdules.

In the burn 1200 yds. south-west of Carn nan Aighean, near the head of Strath Rusdale, a green schistose band which seems to transgress the Moine rocks, though not very clearly, and to occupy a line of displacement, is of a very unusual type, being of a somewhat acid character. It contains both muscovite and biotite, and, in Dr. Flett's opinion, may perhaps represent a sheared felsite or syenite rock (10383).

A crag section a mile and a quarter slightly east of north of Deanich Lodge shows a band of biotite schist, from 1 to 3 ft. thick, which is somewhat steeper than the Moine schists at its sides. This is displaced 60 or 70 yds. along a nearly horizontal thrust, which is accompanied in places by patches of a crushed reddish igneous rock, containing a good deal of biotite, which probably belongs to the lamprophyre group. It is probable that the reddish rock represents an intrusion which has been intruded along the thrust and then crushed by later movements along the thrust.†

It has been noticed almost everywhere in this district that intrusions in the form of biotite schist, as in the steep band just mentioned, are also somewhat calcareous and frequently contain grains of some carbonate, both scattered through the rock mass and collected together with quartz into little strings. It is clear in many localities that the interior portions of intrusive sheets consist of hornblende schist, with little or no admixture of biotite, while the marginal portions are composed of calcareous biotite schist with little or no admixture

* Similar rims are common in the hornblende schists of the Lewisian Gneiss. See, for instance, 'The Geological Structure of the North-West Highlands,' *Mem. Geol. Survey*, 1907, pp. 118, 210, 242.

† It will be mentioned again in connection with the Newer Igneous Rocks in Chapter VII.

of hornblende. It has been noticed also that these marginal portions have frequently been specially disturbed, the foliation therein being much crumpled or crossed by small thrusts, while in the interior portions the foliation of the hornblende schist is much more regular. These phenomena suggest that the marginal portions, composed of calcareous biotite schist, have been developed out of hornblende schist during folding and shearing movements which have specially affected the sides of the intrusions. During these movements, biotite and a ferriferous carbonate seem to have taken the place of hornblende,* but have themselves been crumpled before movement ceased.

The sheet already referred to on the south side of Bodach Mor shows very well the change described. About 1333 yds. S.S.W. of the top of the hill the interior of the sheet consists of hornblende schist with but little biotite: the foliation planes are tolerably even in this portion, and no carbonate is discerned. But about a foot below the top of the sheet the rock changes into a contorted biotite schist which contains little or no hornblende, but a good many thin veins and lenticles of ferriferous carbonate, which are twisted together with the foliation. The change is somewhat rapid, being completed within a thickness of three inches. In another locality, about 1233 yds. S.S.W. of the hilltop, the middle and bottom portions are exposed but not the top, and the bottom is a twisted calcareous biotite schist, while the middle is a hornblende schist without any distinct contortion.

Somewhat similar instances of change from hornblende schist into calcareous biotite schist are well seen at the following localities: burn 700 yds. north of the outlet of Lochan Pollaig, east side of the River Carron about half a mile below the foot of Glen Calvie,† and again 660 yds. below.

In the burn a mile S.S.E. of the outlet of Lochan Pollaig a little sill is exposed, the outer portions of which consist of a soft shivery biotite schist which passes gradually towards the interior into a hard hornblende schist. The weathered biotite schist is not calcareous, but unweathered samples would probably prove to be so, for the usual effect of superficial weathering in these schists is not to develop carbonates but to carry them away in solution.

In Lubachlaggan burn, about 466 yds. south-east of the foot of Loch Toll a' Mhuic, the Moine schists are very steep and considerably twisted, while the margin of a chlorite schist which in places cuts them is more regular. Perhaps this chlorite schist should be classed with the sheared bands of the Newer Igneous rocks.

In areas where the Moine schists are deeply weathered, as described in Chapter II., the hornblende schists are also often in a similar condition. The bottom part of a sill in the burn a mile slightly south of east of Bodach Mor is changed into a soft ochreous rock with large

* For parallel instances in the Lewisian Gneiss see 'The Geological Structure of the North-West Highlands,' *Mem. Geol. Survey*, 1907, pp. 209–210, 241–2.

† It is now known that the centre of one of these schists is not a typical hornblende schist, but contains a good deal of biotite in addition to pale green hornblende, which is being replaced by chlorite and carbonates. Dr. Flett states that it does not seem to be a lamproschist (Chapter VII.) as it is garnetiferous. The edge rock is a calcareous mica schist, with much biotite but without hornblende. Possibly we are dealing with a set of composite sills. See analyses in *Summary of Progress of the Geological Survey* for 1911.

flakes of bleached biotite, while the top is less altered and shows distinct hornblende. In another burn, rather more than a mile slightly south of west of Bodach Mor, the whole of a band about 12 ft. thick is in much the condition of the bottom part of the sill just referred to. C. T. C.

In one of the deep rocky burns on the western flanks of Beinn a' Chaisteil a greenish sill-like band occurs, which, though provisionally classed with the intrusive rocks of the older series, may possibly not represent a true igneous rock at all, but a "Green Bed" of sedimentary origin like those in the Southern Highlands.* This greenish band lies in a locality where the rocks are less sheared than elsewhere, as described in Chapter II., and is only a short distance from a grey phyllite still showing the lines of bedding crossed by the schistosity. It is weathering deeply into a green earth containing much epidote and iron ore, but the freshest specimen obtainable (10446) is reported on by Dr. Flett as "a fine quartz muscovite schist with granules of epidote, sphene and iron oxide. There are a few larger crystals of brown biotite, which cross the foliation obliquely and are obvious in the broken surface of the hand specimen. The rock is a very perfect schist. There is nothing to show that it was originally igneous." This band occurs along the strike of some hornblende biotite schists, and in a neighbouring burn one of these contains large flakes of brown biotite like those referred to above. While the field survey was in progress, the rock described by Dr. Flett was considered to represent one of these schists in an area of low metamorphism. If this view be correct, the results of the microscopic examination would suggest that some of these hornblende biotite schists † have had a sedimentary origin, the hornblende being constructed during a period of metamorphism, as in some of the more altered "Green Beds" of the Southern Highlands.‡ Hornblende schists are abundant along the strike of the schists between Aultguish and Deanich, and also in the Kildermorie Forest, but are apparently very scarce or absent in the quartzose series lying to the east of the band of muscovite biotite gneiss, which crosses Strath Rusdale and Ben Wyvis. C. B. C.

B. *Intrusions in the Plutonic Masses.*

These intrusions seem always in the form of dykes foliated parallel to their sides. They are never more than 10 or 12 ft. thick, and have never been traced more than a few hundred yards. They consist of hornblende schist, hornblende biotite schist or biotite schist, being frequently richer in biotite than in hornblende. The foliation is often finer and closer than that in the earlier basic rocks of group i., or in many of the intrusions of division "A." With this quality may perhaps be connected the great abundance of biotite and the calcareous character often found.§ In crags they always give rise to little nicks, as they yield to weathering more readily than do the adjacent plutonic rocks, most of which are less closely foliated.

The general greater intensity of the foliation in the dykes of this

* See, for instance, 'The Geology of Cowal,' *Mem. Geol. Survey*, 1895, p. 37.
† Others in the same district show indications of an intrusive character.
‡ See, for instance, 'The Geology of Mid Argyll,' *Mem. Geol. Survey*, 1905, p. 19.
§ See preceding description of division "A."

division compared with that in many of the intrusions belonging to division "A" may, perhaps, be due to the fact that divisional planes comparable to those represented by the sides of the dykes were probably rare in the plutonic masses at the time the shearing movements began, while in the surrounding sediments divisional planes were common, in the form of bedding planes. In the plutonic masses, therefore, the shearing movements would be specially apt to proceed along the dykes. These shearing movements have not only led to the production of foliation in the dykes but have also powerfully modified the granitic gneisses at their sides. An instance of the modification has been already described in an earlier part of the chapter, but many other instances of a similar kind could be cited, in which, as the side of the dyke is approached, the foliation in the gneiss gradually becomes steeper and is dragged into parallelism with the dyke side: at the same time the foliation planes become much closer together, and the general colour of the rock changes from pink to dirty white. As far as known, there is nothing to show that the dyke rocks were in a less solid condition at the time of their foliation than the adjacent gneiss was. The general greater intensity of foliation in the dyke rocks seems sufficiently explained by the supposition that the dykes formed special lines of weakness.

These dykes are seen best in the crags on the south side of Diebidale in the Carn Chuinneag plutonic mass. About half a mile south-east of Mullach Creag Riaraidh, where they are sometimes so thickly crowded that it is impossible to show them all in the one-inch map, the general direction is not far from east and west, and the inclination is steeply south. A little further west, in the crags north of Leaba Bhaltair, two of the dykes run nearly north and south, and the widest one is as much as 12 ft. wide.* In the river north of Creag Illie several thin dykes striking W.N.W. are of particular interest, as they cut a confused mass of earlier basic and granitic rocks: the distinction between the basic dyke and the earlier basic rocks is greatly facilitated by the absence of any granitic strings in the former. Most of these Diebidale dykes keep nearly straight as far as they can be traced, but two, on the south-east side of Mullach Creag Riaraidh, have been somewhat twisted, together with their foliation planes.

Outside Diebidale, only one dyke of this division has been noticed within the Carn Chuinneag mass. This occurs in the burn three-quarters of a mile west of the northern end of Loch na Glasa. It strikes north-west, is 6 or 7 ft. wide, and foliated parallel to its side, like the rest.

In Allt an Eilein Ghuirm, in the Inchbae plutonic mass, several thin bands of biotite schist, often calcareous, appear to represent intrusions later than the granite gneiss. Like the Diebidale dykes, they have often acted as lines of weakness along which shearing movements have proceeded, that have not only sheared the bands themselves but also greatly modified the augen gneiss at their sides. A band of this kind is seen nearly three-quarters of a mile above the burn foot, and three others occur close together rather less than a mile above the foot. All these appear to strike W.N.W., but, owing to the covering of drift, they cannot be traced outside the burn. C. T. C.

* The analysis of this dyke is given in Chapter VI.

CHAPTER V.

CONTACT-METAMORPHISM PRODUCED BY THE OLDER GRANITE.

Introduction.

In 1900, Dr. Peach noticed a certain amount of contact-alteration in thin pelitic bands in the siliceous Moine schist at their junction with the granite mass of Inchbae. He made the following statement in the *Summary of Progress of the Geological Survey* for that year: "The granite appears to have produced a certain amount of contact-alteration in the schists, though this early metamorphism is now masked in part by the structures that have been induced both in granite and schist by the pressure to which they have been alike subjected, and to which in great part, if not wholly, their present crystalline condition is due."

It is, however, where the thick band of pelitic sediment comes into contact with the granite of the larger Carn Chuinneag mass that the effects of contact-metamorphism are most clearly seen. This granite is in contact with rocks of pelitic character along all its border except at the south-west end (Plate XII.), where it abuts against more siliceous types.

The pelitic rocks have been contact-altered over wide areas, and usually form a broad belt of hornfels fringing the granite outcrop. This belt was first encountered in 1901 near Kildermorie, where the hornfels forms a conspicuous crag on the northern shoulder of Meall nam Bo, and is also well exposed in the bed of the Abhuinn na Glasa, between Kildermorie Lodge and the eastern margin of the augen gneiss, which crosses the stream about half a mile above the Lodge. Other good exposures are seen in the small crags on the slopes overlooking the stream between these points. These exposures of the hornfels, and especially that on the crag north of Meall nam Bo, form a striking contrast to the neighbouring Moine schists. The attention is immediately arrested by their bluish colour, homogeneous appearance, and south-westerly dip at right angles to the general direction of dip in the schists, which is south-eastward. Shortly after the discovery of the hornfels at Kildermorie, Dr. Peach suggested that the pelitic sediments had been contact-altered by the granite previous to the movements which have altered the surrounding sediments into schists and converted the granite into a gneiss, and, further, that these hornfelsed sediments, owing to their contact-alteration, had escaped the dynamic metamorphism in which the unaltered sediments and the granite have subsequently been involved.

Specimens of the hornfels from Kildermorie were submitted to Dr. Flett for petrological examination, and were stated by him to show no sign of mechanical deformation.* Further field work showed that where

* *Summary of Progress of the Geological Survey* for 1901, p. 108.

these sediments are of pelitic nature, they have been contact-altered and hardened for a considerable distance from the granite margin, but, at a subsequent period, all the rocks have been subjected to powerful tangential pressure, and the greater part of the sediments and the granite have together been foliated and metamorphosed into schists and gneisses. The great hardening and mineralogical alteration undergone by those parts of the pelitic sediments which were within the aureole of thermal metamorphism, probably caused parts of this hornfelsed zone to move *en masse* during the processes of folding and foliation which the other rocks have undergone, and thus preserved these parts from mechanical deformation and regional metamorphism. The band of pelitic sediment which is in contact with the granite gives a wide outcrop, and is evidently of considerable thickness, but those parts of it which are furthest removed from the granite, and which probably lay outside the original limits of its thermal alteration, are over wide areas in the condition of mica schist. Within the contact-aureole the hornfels is traversed by planes of shear.

Mica schists have been produced by the shearing of the hornfels, but the schists so produced can usually be distinguished from those lying outside the contact-aureole. They generally retain, for instance, some of the blue colour of the hornfels and are never coarsely crystalline.

It may be pointed out that phenomena of a somewhat similar character to those observed near the Carn Chuinneag granite had been previously met with by Mr. George Barrow, in the neighbourhood of the Ben Vuroch granite, north of Pitlochry.* Mr. Barrow appears to suppose that a thermal alteration like that observed near Ben Vuroch once affected the rocks over a very large area, too large to allow it to be attributed to a localised granite intrusion. He came to the conclusion that the unfoliated hornfels owed its preservation from shearing chiefly to the shelter afforded by the granite. The hornfelsed rocks of Ben Vuroch are chiefly found on the western side of the granite, which is the lee-side, in reference to the schist-making movements of that district.

The phenomena near the augen gneiss of Ross-shire indicate rather that in this area the thermal metamorphism was limited to the neighbourhood of the granite, and that it was the physical and mineral constitution of the altered rock which chiefly led to its preservation from the deforming influences of the subsequent movements. The largest areas and finest sections of hornfels lie on the eastern side of the granite mass, the side facing the quarter from which the tangential movements took place, the isoclinals of the schists generally dipping east. There is, indeed, reason for thinking that in this area also some of the more coarse-grained granite has locally offered more resistance to dynamic metamorphism than the sediments which were not thermally altered by its intrusion. It is probable, however, that some degree of protection was afforded to the granite by the hornfelsed sediments along its margins, but the frequent evidence of shearing of the hornfels along the granite margin shows that the hornfels and the granite did not everywhere act as one rigid mass. C. B. C.

It ought to be stated that the shearing of the hornfels may have proceeded at more than one period. It is probable, as will be subse-

* 'The Geology of the Country round Blair Atholl, Pitlochry, and Aberfeldy,' *Mem. Geol. Survey*, 1905, pp. 91–94.

quently shown in describing the district of Glen Calvie and Cnoc an t-Saic, that some of this shearing may be later than the intrusion of certain lamprophyres. This later shearing is, however, probably confined to small areas in the vicinity of thrusts along which repeated movements have taken place. C. T. C.

Types of Hornfelsed Sediment.

To the naked eye most of the hornfels has a peculiar dark bluish colour and a very fine-grained texture. It is frequently finely banded or striped with darker and paler bands, which mark slight differences due to original sedimentation. The rock breaks up into cuboidal fragments, or else the fracture is conchoidal, resembling that of a fine-grained igneous rock. Locally, fairly large slabs or flags occur which show silvery partings of white clastic micas, separated by thin lenticular sandy laminæ, and, on these slabs, surface markings are occasionally observed which have a close resemblance to the sun-cracks of more recent sedimentary rocks. No trace of fossils has been found, though from the small amount of deformation the rocks have undergone they would be likely to have been preserved if originally present. From the unusual distinctness of the very fine lamination, it seems probable that differences in original laminæ of sedimentation have been accentuated to the eye by the thermal alteration, in the manner pointed out by Mr. Barrow in the hornfels of the Ben Vuroch area. Those types which show the original bedding clearly and are rich in white mica may be classed as *knotenschiefer*, being abundantly spotted with small specks and knots, which are stated by Dr. Flett to consist of clustered scales of pale mica. Many specimens have been found to contain sillimanite in tufts, and chiastolite. The last named mineral occurs in a definite band of a darker colour than that usually met with, and, as Dr. Flett detected specks like carbon in this rock, the darker colour may perhaps be due to original greater organic impurity. Sillimanite is widely distributed in the hornfels, and occurs in specimens up to the granite margin and even in the granite itself, perhaps in consequence of absorption of some of the sedimentary material. Garnets, spongy with quartz enclosures, are not uncommon in the hornfels. They usually occur in special abundance along certain bands, and along the south-east margin of the granite they are largest and most frequent in the rocks in close contact with it, where the rocks have clearly suffered some deformation and are now more or less schistose in character: it is to be noted that the garnets themselves are also frequently deformed. Chiastolite prisms are also found, but only in certain bands, presumably those which originally possessed a chemical composition particularly favourable to their development.

The Distribution of the Hornfels and its Relation to the Granite and the Moine Schists.

The crops of the hornfels are confined to the neighbourhood of those parts of the margin of the granite which are in contact with

the pelitic sediments. These sediments form a belt following the granite margin from Beinn nan Eun, about the middle of the south-east margin, north-eastwards through Sgor a' Chaoruinn, Kildermorie, Carn Cas nan Gabhar and Meall Bhenneit. Thence the belt curves round the northern boundary of the granite at Carn Bhren and Carn Salochaidh, and extends nearly as far south-west as Beinn Tharsuinn. The crop thus extends along considerably more than half of the boundary of the Carn Chuinneag granite, and has a total length along the curve of 20 miles. The width of the band between Beinn nan Eun and Carn Cas nan Gabhar averages nearly a mile. On the northern margin near Carn Bhren it is about the same, but gradually diminishes from this place south-westward till it dies out against the granite near Beinn Tharsuinn. On the south flank of Beinn nan Eun the outer margin of the pelitic band turns abruptly to the N.N.W., striking almost at right to the granite boundary. By consulting the map, it will be seen that the continuation of this line across the granite mass will strike the north-west margin of the granite at the point where the pelitic mass there comes to an end. The present outcrop of the pelitic mass consists, therefore, of the outer rim of a lenticular outlier about nine and a half miles in length in a north-east and south-west direction and six miles in breadth, the granite occupying the centre and four miles of the south-west part of the rim, where it passes from the pelitic into the surrounding siliceous rocks. Although the pelitic gneiss outcrop hugs the granite, as shown above, it is probable that the whole breadth was not within the aureole of thermal metamorphism.

Detailed Descriptions of Districts.

Kildermorie to the south side of Meall na h-Uigeig.

Within the pelitic belt from Kildermorie north-eastwards a line has been drawn separating an inner belt of hornfels from an outer belt of mica schist. This line can be first traced on Meall Toll a' Choin, near Kildermorie, and thence extends several miles, more or less parallel to the adjacent margin of the pelitic band, across An Claigionn and Bad a' Bhathaich, on to the eastern shoulder of Meall Bhenneit. The band of mica schist south-east of this line is in several places a quarter of a mile in width, but the hornfelsed rocks between this line and the granite margin are usually over half a mile, and for some distance north of Kildermorie fully three-quarters of a mile in width.

It is probable that the greater part of the pelitic belt between Bad a' Bhathaich and Meall na h-Uigeig has at one time consisted of hornfels, though much of it has been considerably altered by subsequent movement and has been changed into mica schist. The line drawn on the map from Bad a' Bhathaich north-eastward to Meall na h-Uigeig must not, therefore, be taken to indicate the original extent of the aureole of thermal metamorphism, though the line between Bad a' Bhathaich and Kildermorie does perhaps nearly do so. The influence of the granite may have extended somewhat further, but the sediments outside this line have yielded to the subsequent movements to the same degree, and have been as much altered

by dynamo-metamorphism as any of the pelitic beds far removed from the thermally influenced area. The mica schists outside the line between the points last referred to are similar to those which form the isolated outcrop on Carn Beag, $1\frac{3}{4}$ miles east of Kildermorie. They are dark grey in colour, and contain fairly large plates of mica, including biotite. The rock is distinctly foliated, and contains many thoroughly granulitic quartzofelspathic streaks and lenticles, and the foliation planes are minutely puckered, causing the rock to split along corrugated division planes. In sections across the foliation, the puckering of the darker micaceous and lighter quartzofelspathic layers is well seen, and it is apparent that the original material has suffered a distinctly higher grade of regional metamorphism than the blue phyllites and silky mica schists that have in many places been produced by destruction of the hornfels.

On An Claigionn and Meall Toll a' Choin, where this mica schist is well seen, the bedding planes cannot be easily distinguished, but the foliation is contorted, and the axial schistose planes are more or less vertical and strike N.N.E. and S.S.W., the same direction as in the other schists in the vicinity. This mica schist was observed as far north as the march fence running between Carn Cas nan Gabhar and Loch Bad a' Bhathaich.

The line of passage from mica schist to hornfels on approaching the granite from An Claigionn and Meall Toll a' Choin is well defined, since the hornfels is bluish in colour, and is dipping uniformly in a southerly direction at angles of 20° to 40°. The dip becomes more gentle near Carn Cas nan Gabhar, being only 2° to 3°.

This direction of dip is maintained in the hornfels from the crag south of Kildermorie as far north as Carn Cas nan Gabhar, and is remarkable, since the strike of the beds makes a great angle to the granite margin on the W.N.W., and also to the general strike of the folds and foliation in the schists to the E.S.E. Where the hornfels is well exposed it is generally of the spotted type and usually contains sillimanite, and the bedding planes can be traced for long distances maintaining their E. and W. strike, and without any sign of folding. In several places between Kildermorie and the margin of the granite, thin lines of shear parallel to the foliation of the schists occur, the rock at the same time becoming a glistening phyllite, somewhat bluish but lighter in shade than the hornfels.

North of Bad a' Bhathaich, although a boundary line has been drawn, as described above, the separation of the mica schist from the hornfels is difficult, since that part of the pelitic band furthest removed from the granite is largely in the condition of a pale bluish phyllite in which the micas are barely visible to the naked eye, and the complete segregation and foliation of the minerals seen in the mica schist of An Claigionn are not found. A good section of these phyllites is exposed in the small burn running north from Bad a' Bhathaich to join the Amhainn Glac an t-Seilich. Many of the phyllites exposed in this section have the bedding planes still preserved but crossed by planes of schistosity. The separation of the hornfels from the phyllite is also rendered more difficult, as north of Carn Cas nan Gabhar the dip in the hornfels gradually swings round to the S.E. and E.S.E., thus bringing the strike of these rocks more or less parallel with that of the cleavage in the phyllites, and of the folds and foliation in the schists. It would appear that the rocks which are

now in the condition of phyllites lay within the aureole of thermal metamorphism and were previously hardened and hornfelsed, and so have escaped to some degree the intense mechanical metamorphism that has produced the mica schists of An Claigionn. These phyllites are like those seen in the planes of shear, and have probably had a similar history.

North of the Amhainn Glac an t-Seilich the hornfels retains its S.E. and E.S.E. dip at angles of 10° to 20°, and the rocks may be studied on the northern flank of Meall Bhenneit and the bed of the Allt Coire Bhenneit. A marginal zone of phyllites and fine-grained mica schists flanks the hornfels on its south-eastern side, but the rock still preserved as hornfels has suffered little movement, and belongs to the *knotenschiefer* type (slides 9870–9875, 9865, 9868). In the Allt Coire Bhenneit a finely preserved hornfels breaks up into large slabs along the bedding planes, which are bright with scattered clastic micas, and crossed by suncracks filled with sandy material. The original sandy layers in the pelitic sediment are also unusually thick and conspicuous.

The rocks in contact with the granite are well exposed in the bed of the stream west of Kildermorie Lodge, and to the north as far as Carn Sonraichte. The rocky top of Carn Cas nan Gabhar, and the prominent crag north of the road to Lochan a' Chairn, also afford good sections of the junction. At all these localities the hornfels suffers much contortion at distances of about 200 yds. from the granite, and nearer to the granite the contortion increases, and in the immediate vicinity the rocks are thrown into a more or less vertical position, sometimes dipping towards and sometimes away from the granite. A well marked schistosity is present in these upturned rocks (9866), and large garnets are often conspicuous, standing out on the weathered surfaces. The schistosity is in the same plane as the original bedding. The granite at the margin is always foliated, and the vertical position of the rocks must have been caused by pressure against the granite during the later regional movements.

These schistose rocks are blue in colour, like the hornfels, and usually extremely fine-grained. The garnets, which are frequently larger than peas, are red, but spongy with quartz enclosures. The finely divided micaceous matrix often appears to wrap round the garnets, which then resemble augen.

SGOR A' CHAORUINN AND BEINN NAN EUN.

The rocks in this area are, as elsewhere, partly in the condition of hornfels and partly of mica schist, the rocks in the immediate vicinity of and those furthest from the granite being schistose in character. The distribution of these two types is, however, so irregular that lines could not be satisfactorily drawn to separate them on the map. Good sections of hornfels are exposed along the crest of Sgor a' Chaoruinn, on the north shore of Loch a' Chaoruinn and on Beinn nan Eun. Where the hornfels is preserved the strike of the beds is nearly at right angles to the granite margin and to the strike of the neighbouring schists. On the summit of Sgor a' Chaoruinn, and southward towards Loch Magharaidh, the dip is at 10° to 30° to the S.W. and W.S.W., but further south, on Beinn nan Eun, the

dip is to the N.E. and E.N.E., so that there is a synclinal arrangement of the beds between these points. The hornfels is for the most part a knotted hornfels, as at Kildermorie, but in places well preserved purely sandy beds, now in the condition of white quartzite, emphasise the bedding. On one of these quartzite bands, on the slopes south of Loch a' Chaoruinn, surface markings like ripplemarks were observed. Both on the crest of Sgor a' Chaoruinn and on Ben nan Eun these quartzite bands underlie a peculiar dark pelitic band containing minute garnets and numerous pale forms resembling crystals with oblong and square sections. The square sections often have a well-defined cross suggesting chiastolite, and Dr. Flett considers the mineral to be a pseudomorph after chiastolite (11021, 11022, 11232). Slide 11232 also contains a mineral which appears to be kyanite. This band of rock is readily identified, and has been traced about a mile in the northern locality, and for some distance on Beinn nan Eun. Its relation to the underlying quartzose bands in both localities, together with the regular synclinal arrangement of the rocks in this locality, indicate that the exposures of the chiastolite hornfels in the two localities are probably parts of the same band. In the low ground east of Loch Magharaidh the band was not recognised, but this is probably owing in part to the rarity of exposures, and partly to the fact that the more striking features of the rocks are obliterated by shearing movement. Such an obliteration becomes evident on tracing the band on Sgor a' Chaoruinn. The band can be traced with a north-west and south-east strike across the summit of this crag and down the north and south flanks for about half a mile, dipping steadily to the south-west. At its south-east extremity it abruptly twists nearly at right angles to its former course, and assumes a S.S.W. strike and W.N.W. dip, and simultaneously with the change of strike becomes a dark, fine-grained mica schist with large garnets.

At its north-west extension the band is also deflected suddenly to the N.N.E., and at the same time the chiastolite pseudomorphs become indistinct, and the rock passes into a fine-grained blue schist containing "spongy" garnets, sometimes as large as peas. In the upper part of a little bank, 200 yds. S.S.W. of the west end of Loch a' Chaoruinn, the undeformed hornfels contains many straight white prisms, nearly an inch long, in association with small round *knoten*, but in the lower part, only two or three feet below, the rock is a bluish crumpled garnetiferous mica schist, in portions of which the remains of the prisms can still be discerned, but often in a bent condition, or even puckered into small "v's" (Plate IV. Fig. 2): the garnets also have suffered from the schist-making movements, their outlines being often rounded and bordered by quartz rims.

A loose block of mica schist, found in Amhainn Glac an t-Seilich, shows the deformation of somewhat similar long prismatic forms in an unusually clear manner. These forms (10957) are now chiefly occupied by white mica, but they have black cores, as chiastolite often has.

On Beinn nan Eun the band of chiastolite hornfels could not be traced into mica schist owing to the drift cover on the slopes of the mountain. The rocks along the granite boundary in this area are only well exposed between Creag Liath a' Bhaid Sgailich and Carn

Feur-lochain, where they are nearly vertical. A schistosity is well developed in them and in the granite in contact with them. The planes of schistosity dip to the south-east away from the granite margin, and so conform with the dip of the axial planes of the overfolds of the schists in the neighbourhood. A nearly vertical arrangement of the beds near the granite is also seen on the western flank of Beinn nan Eun, but the junction of the rocks is obscured by drift.

We may next consider shortly what field evidence there is concerning the disposition and condition of the sedimentary rocks at the time of the intrusion of the granite. There is only one set of planes in the well preserved hornfels, and that these planes are bedding planes is shown by the surface markings on some of them, and by their general parallelism to thicker bands, of different composition, which undoubtedly represent sediments of a different class. The simple synclinal arrangement of the hornfelsed rocks in the area between Beinn nan Eun and Sgor a' Chaoruinn is well brought out by the chiastolite hornfels, and proves that previous to the intrusion of the granite the sediments had not been subjected to lateral compression sufficient to produce overfolding. We may conclude, also, that no slaty cleavage had been developed, in view of the absence of any sign of deformation affecting the bedding planes, whether they be dipping south-west or north-east. The effect of thermal metamorphism on any cleavage or shear-planes which already existed would probably be to emphasize them, by adding a greater colour contrast, rather than to destroy them.

Only where shales were within the thermal influence of the granite was a hornfelsed rock produced, which has partially resisted the later regional metamorphism. The largest areas of unsheared hornfels are found along the eastern margin of the granite where the pelitic belt is widest. In consideration of the direction of overfolding in the schists, the cause of the protection of the hornfels from shearing cannot be sought in resistance to movement on the part of the granite mass. The evidence of shearing of the hornfels along the granite margin also indicates that the granite and the hornfels did not act as one rigid mass which resisted deformation. The cause of the resistance of the hornfels to subsequent metamorphism must mainly lie in its physical and mineralogical constitution, but other causes may also have helped to the same end. It may be noted that the strike of the beds in the largest area of well preserved hornfels lies at right angles to the strike of the regional movements. Whether these beds had this strike at the time of the intrusion of the igneous rock it is difficult to say, but it is very unlikely that it was impressed on them during the later movements. C. B. C.

District of Strath Rannoch.*

On the west slope of Beinn nan Eun the granite of the Carn Chuinneag mass is bordered directly by siliceous Moine schist, but west of Abhuinn Beinn nan Eun a thin margin of pelitic material again comes in. It is shifted nearly a mile to the south-west by the large wrench fault which runs past Loch nan Amhaichean (see Chapter IX.),

* The southern boundary is taken rather further south than that of the district with the same name in Chapter II.

but reappears bordering the granite on the north slopes of Carn Loch nan Amhaichean. It then disappears under the overlying deposits of Old Red Sandstone and Conglomerate, and where the granite is next seen in contact with the schist (on Meall nam Mullach) this border is entirely absent. In this particular area the pelitic border never attains more than a small part of the width which it shows to the north-east of Beinn nan Eun, but for all that it is possible that it may in part represent the same horizon. We may in fact suppose that the margin of the sill or laccolite of granite, after transgressing the band of pelitic material in one direction, transgresses it again to a smaller extent in the opposite way.

Both within the pelitic border in this area and without it, wherever a thinner band of pelitic material occurs amidst the siliceous schists, the rock is mostly hornfelsed. It presents in general a knotted or nodular appearance, and two types may be distinguished, according to the fineness of this knotted character.

The first type is finely knotted, and under the microscope shows little patches of sillimannite (11210), which often occur in the centres of the knots. The second type is also knotted, but more coarsely crystalline than the first (11213). The knots resemble nodules and are about as large as peas, but frequently drawn out into an ellipsoidal form by movement subsequent to the hornfelsing. Sillimanite is not present, and the knots seem to consist of accumulations of little flakes of brown and white mica.

About 500 yds. S.S.W. from the summit of Carn Loch nan Amhaichean some loose blocks of hornfelsed material were found, containing well-marked pseudomorphs after andalusite. These blocks, though loose, were evidently not far displaced. The pseudomorphs consist of kyanite, white mica and quartz (11208 and 11209).

E. M. A.

The relations of the foliated granite of Inchbae to the surrounding schists are well seen on the summit and northern slopes of Carn Mor, two miles N.N.E. of Inchbae Lodge. The margin is a complex one and presents a plexus of igneous and metamorphic rocks.

The usual contact-phenomena of the granite can be observed when it is in contiguity with the originally more argillaceous or semipelitic members of the Moine Series. These have been altered into garnetiferous sillimanite biotite hornfels, with an occasional sporadic development of andalusite crystals.

L. W. H.

DISTRICT OF GLEN CALVIE AND CNOC AN T-SAIC (CNOC NAN SAC).

This district includes nearly all the area, within the one-inch map, which drains into the river Carron below the foot of Alladale River. It also extends a mile or two south-west of Beinn Tharsuinn (Diebidale). The eastern boundary is drawn through Carn an Liath-bhaid and Creag na Ceapaich.

The broad pelitic band which keeps along the granite boundary from Carn an Liath-bhaid, in a west and south-west direction, almost to Beinn Tharsuinn, is in a hornfelsed condition in many localities, which are for the most part roughly indicated on the one-inch map. Presumably the hornfelsed beds were by the hornfelsing so welded

together that large portions of them moved as units in the subsequent folding, and escaped the shearing actions going on around them. The hornfelsed rocks which entirely escaped shearing are connected with the normal schists by many intermediate varieties, which were first hornfelsed and then sheared, but not so greatly as to obliterate the "*knoten*" previously developed. The unsheared hornfelsed rocks still allow us to discern the original characters of the rocks from which they were formed—chiefly muddy sediments with thin sandy laminæ containing small clastic grains of quartz and felspar. In the crags on the east side of Mullach Creag Riaraidh, the clastic grains in some of

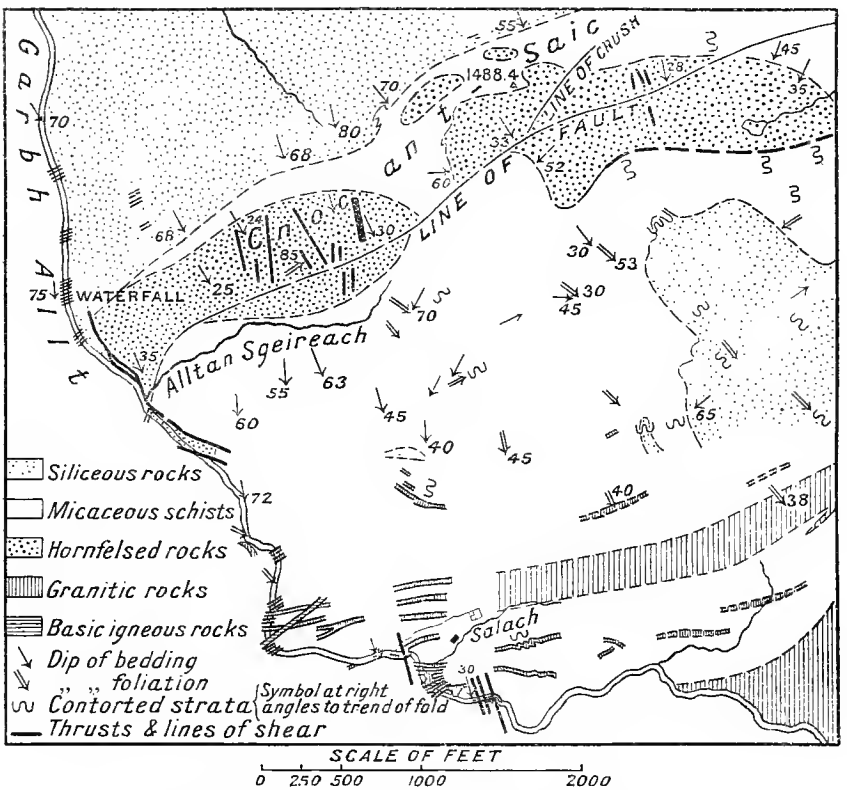


FIG. 10.—Map of the district between Garbh Allt and Cnoc an t-Saic (Cnoc nan Sac).

the gritty laminæ show no appreciable deformation, though the "*knoten*" in the more pelitic portion are considerably elongated. In the same crags some of the bedding surfaces of the hornfels show small ridges resembling ripplemarks.

The hornfelsed patches which are most free from schistosity occur in the following localities:—The burn rather more than half a mile south-west of Cnoc an t-Saic; the hillside extending a quarter of a mile north-east of this burn; south-east and east of the top of Cnoc an t-Saic; close to the granite half a mile W.N.W. of Carn an Liath-bhaid; two-thirds of a mile slightly west of north of Carn an Liath-bhaid; parts of Carn Bhren. Where the hornfelsed character is most

pronounced the pelitic or semipelitic rocks are extremely tough, can hardly be broken along the bedding, even where this is quite distinct, and contain abundant small grey spots, "*knoten*," often about the size of rape seed, together with pink idiomorphic garnets of about the same dimensions. Microscopic examination often discloses the presence of sillimanite also. Scars usually weather with a rusty colour owing to the abundance of thin streaks of pyrites. In those places where the "*knoten*" are spherical, the angle of dip is often no more than 15° or 30°, and there is no evidence that the beds have ever been folded. Rocks of this type pass, along planes of shear and thrust, into others which are distinctly schistose, containing garnets with rounded edges, and "*knoten*" which have been flattened and elongated, frequently across the bedding planes.

The annexed map (Fig. 10) shows various shear zones and thrust lines in the area near Cnoc an t-Saic. The closely adjoining lines on the south-western portion of the hill strike nearly N.N.W., and are approximately vertical. They have generally given rise to gulleys in consequence of the softness of the sheared stripes compared with the hornfels at their sides. In the sheared stripes the bedding is vertical and strikes about N.N.W., while in the neighbouring hornfels it generally dips S.S.E. at 25° or 30°. The hornfels close to the sides of the sheared stripes is itself usually somewhat modified, being crossed by a weak vertical foliation parallel to the stripes. The rocks in the N.N.W. shear zones and thrusts just described, though they are lustrous and schistose, are not so thoroughly schistose as the normal Moine schists.

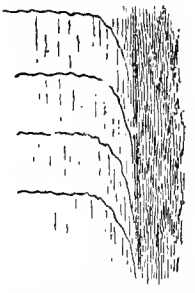


Fig. 11.—Diagram of Vertical Thrust in Garbh Allt.

Vertical thrusts striking N.N.W. are also seen in Garbh Allt, rather more than two-thirds of a mile south of the top of Cnoc an t-Saic, where they affect both the sediments and thin sheets of granite, in somewhat the same way as the pre-Torridon thrusts of West Sutherland affect the Lewisian Gneiss. Some distance off the thrusts the sediments are represented, not by hornfels like that mentioned in the preceding paragraph, but by rather thick, somewhat indistinctly foliated beds which are very rich in small flakes of biotite, and have in consequence been called "stippled schists." * These beds strike E.N.E. and dip S.S.E., but on approaching a line of thrust they become vertical and much attenuated, as represented in Fig. 11, and so many new planes of schistosity are developed in them, parallel to the axial planes of various close folds, that the original bedding can hardly be discerned. The rocks which in this locality strike E.N.E. and dip S.S.E. are represented by specimens 11269 and 14155, called by Dr. Flett garnetiferous biotite gneiss and flaggy biotite schist respectively: they show no clear indication of hornfelsing, but are certainly less distinctly foliated than many of the Moine gneisses.

* They are referred to again at greater length on p. 86.

Presumably they have acquired their foliated structure in consequence of movements which proceeded parallel to the granite margin before the N.N.W. thrusts took place.

There is evidence in favour of the view that movements were repeated along these N.N.W. thrusts again and again, and that the later movements took place after the intrusion of some of the igneous rocks of the Newer Series, and converted them into chlorite schists. A contorted chlorite schist on the north side of Garbh Allt, 940 yds. south-east of the foot of the little burn (Alltan Sgeireach, Fig. 10), which runs south-west from Cnoc an t-Saic, occurs along one of these N.N.W. thrusts, and bears a close resemblance macroscopically to a schist which occurs in a horizontal thrust to be shortly described. The green schist in the latter thrust is supposed by Dr. Flett (p. 124), from chemical and petrological evidence, to have been formed out of a rock of the lamprophyre group, and presumably the green schist in the N.N.W. thrust has been derived from a similar rock.

It is probable, consequently, that it belonged to one of the Newer Igneous rocks, which were certainly in many districts intruded after the Moine rocks had already acquired their foliated character. It must be admitted, accordingly, that near the Garbh Allt, as also in other localities, as will be subsequently shown in Chapter VII., a considerable amount of shearing has gone on after the intrusion of some of the Newer Igneous rocks. This shearing has sufficed to convert these igneous rocks into thorough schists, but no evidence has yet been obtained to prove that it also sufficed of itself to make the Moine rocks into thorough schists. We suppose that the initial movements, along the N.N.W. thrust described, took place before the intrusion of the lamprophyre from which the chlorite schist was formed, and it is probable that these initial movements had the chief effect in producing the schistosity at present observed in the Moine rocks near the thrust. A great interval of time may have elapsed between the initial and the latest movements along this thrust.*

Near the top of Cnoc an t-Saic, also, there is further evidence in favour of the view that the N.N.W. thrusts are later than other schist-making movements striking E.N.E., for, though the schists north-west and south-east of the hornfelsed rocks are not crossed by any distinct thrusts, they are in places bent into a N.N.W. strike by twists which may be contemporaneous with thrusts.

The thrusts in the north-east bank of the Garbh Allt south-west of Cnoc an t-Saic (Plate VI. and Fig. 10) are almost horizontal. The best example, that on the north-west of Alltan Sgeireach, is accompanied by a thin seam of contorted unctuous schist which no doubt represents some igneous rock, intruded along the thrust, and subsequently sheared and contorted by renewed movements: parallel to the main seam are others still thinner. Twenty feet above the thrust the pelitic sediments are represented by hard compact hornfels with abundant spots ("*knoten*") without any trace of deformation. As the thrust is approached the spots become pulled out, and splitting planes, coated with small scales of white mica, begin to appear approximately parallel to the thrust. The planes become gradually closer and more

* See W. B. Wright's paper on 'The Two Earth-Movements of Colonsay,' *Quart. Jour. Geol. Soc.*, 1908, vol. lxiv. p. 297.

Nearly Horizontal Thrust Plane, Garbh Allt, rather more than half a mile W.S.W. of Cnoc an t-Saic (Cnoc nan Sac).

and more lustrous, until the rock acquires the character of a true but still rather fine-grained mica schist. For two or three feet above the thrust, the foliation planes and the mica flakes on them are considerably waved. The unctuous schist has been analysed by Dr. Pollard, and examined by Dr. Flett, who considers it to have been derived from some intrusion of lamprophyric type.* It seems, therefore, probable, as in the case of one of the N.N.W. thrusts just alluded to, that movement sufficient to convert an igneous rock into a schist took place along the thrust even after the intrusion of some of the Newer Igneous rocks.

The horizontal thrust just described has displaced the north-western boundary of the hornfels for about 60 yds., the upper side towards the north-west, and it seems certain that, like the N.N.W. thrusts, it is of later date than the movements which gave the north-east strike along this boundary, and changed the rocks there into schists. Further evidence pointing to a similar conclusion is found near one of the horizontal thrusts a little south-east of the foot of Alltan Sgeireach, where a garnetiferous mica schist is folded along nearly horizontal axial planes, and seems to have been already a schist before the folding.

Just on the north-west and south-east sides of the patches of hornfels on Cnoc an t-Saic, some of the schists which strike E.N.E. and dip S.S.E. are indistinguishable from Moine schists found far away from the granite, though other bands still occasionally show greatly deformed spots. These Cnoc an t-Saic schists have much the same strike and dip as other schists extending some miles north of the granite, and it seems probable that these other schists also have been manufactured by movements striking parallel to the adjacent boundary of the granite and somewhat more powerful in kind than any of the N.N.W. thrusts described. Along the south side of the eastern portion of Cnoc an t-Saic the line between the hornfels and the garnetiferous mica schist is well defined and probably represents a line of rupture, striking slightly north of east. Many sharply folded quartz-felspar veins are seen just south of the boundary, and it is evident that earth movements have been repeated on this side again and again.

A line of intense shearing, striking north-east, which affects both sediments and granite, at the sides of a mountain pass about half a mile north-west of the summit of Carn Salochaidh, has already been described on p. 56.

Near Cnoc an t-Saic and Cnoc na Tuppat, and for the greater part of the north side of Diebidale River, the distinctly hornfelsed rocks are, as a rule, separated from the granite by schistose or gneissose rocks, in which no distinct hornfelsed character is observable. These, we suppose, have been formed from hornfels by shearing, and it seems necessary, therefore, also, to suppose that, in the localities specified, shearing movements parallel to the margin of the main granite mass took place more generally near to the junction than a little further off. This does not seem, however, to have been the case in all areas, for hornfels is seen very near the granite on parts of Carn Bhren, and in contact with it at Carn an Liath-bhaid and half a mile W.N.W. of this hill. In the latter locality, in one bed about 6 in. thick, the garnets are as large as peas—considerably larger than those in the other beds

* For further description see Chapter VII.

close to, or in the other unsheared hornfelsed rocks observed in the district.

On Cnoc an t-Saic and Cnoc na Tuppat, two types of rock, with boundaries approximately parallel to that of the main granite mass, come in between the granite and the patches of well spotted hornfels. The type next the granite is represented by specimen 11269, and may be described as a well bedded but not very distinctly foliated rock. Biotite is extremely abundant in this rock, not only in flakes lying flatly along the bedding surfaces, but also, to a less extent, in small scales scattered through the beds, thus giving to cross fractures a peculiar grey speckled appearance, whence the name "stippled schist" has been given, as already stated. The abundance of biotite and its occasional collection into ill-defined small spots are both suggestive of contact-alteration, but, on microscopic examination, these rocks show no clear indications of hornfelsing, and appear to differ but slightly from other Moine gneisses far away from the granite. They often show a foliation crossing the bedding, but, apart from this, it is believed that the prominent splitting planes represent, as a rule, both bedding and foliation planes. The accompanying granitic sills are often distinguished by a rodded structure, but they also occasionally show a plane foliation parallel to the bedding of the sediments. On Cnoc na Tuppat the stippled schists are much mixed with minor granitic intrusions, and the total breadth of crop, including the intrusions, is nearly a third of a mile. On its north-west side, which is tolerably well defined, comes a micaceous somewhat schistose semi-pelitic yellow-weathering rock, which rarely shows distinct bedding but contains abundant garnets, about the size of peas, with rounded edges and often cracked and elongated. In a few localities in the Garbh Allt deformed "*knoten*" can also be perceived, sometimes dragged out in a direction across the bedding. South-west of the summit of Cnoc na Tuppat the garnets are distinctly elongated in one direction, striking west of the dip of the foliation planes, and much the same as that of the elongation of the clastic grains in the siliceous schists three-quarters of a mile south-west of the hill-top. In the same exposures the garnets are repeatedly cracked in a direction at right angles to that of the elongation, and quartz has filled in the cracks and formed new growths at both ends of the deformed pieces.* The elongation and the filled-in cracks are shown in Plate VII., Fig. 1. Though it is thus evident that these garnetiferous rocks have suffered considerably from shearing, they are less fissile and lustrous than true schists: in the type specimens 11227 and 11228, from 983 yds. south-west of Cnoc an t-Saic and 220 yds. south-east of Cnoc na Tuppat respectively, the scales of mica, though parallel, are not collected into separate lustrous folia, but are mixed somewhat uniformly with the other constituents.

Distinct prisms of chiastolite or andalusite have very rarely been observed in the district.

About a quarter of a mile slightly east of north of the top of Mullach Creag Riaraidh the "*knoten*" are flattened and drawn out into ribbons, in a very clear manner (Plate VII., Fig. 2), in a direction which strikes slightly west of the dip of the foliation, and is the same as that of the

* See Harker, 'On Eyes of Pyrites and other Minerals in Slate,' *Geol. Mag.*, 1889, p. 396.

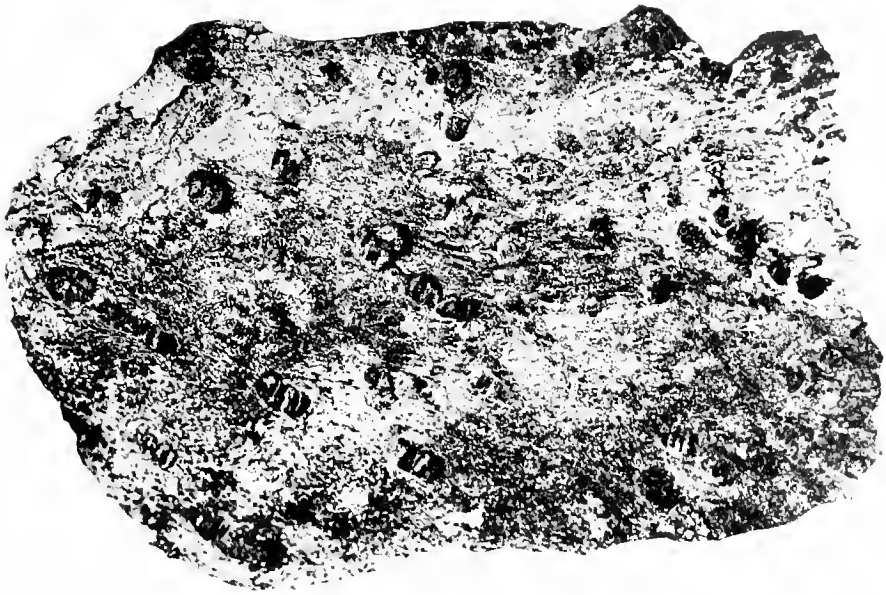
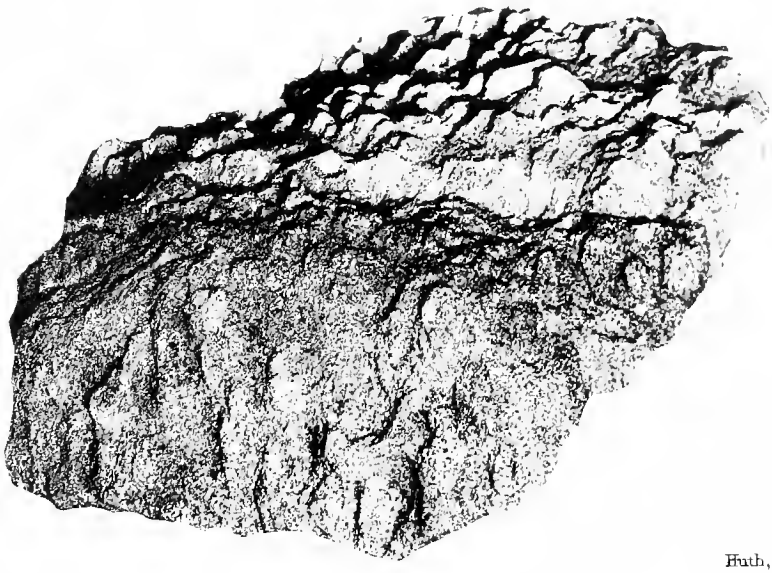


Fig. 1. × 2. Garnetiferous Mica Schist, 200 yards south-east of Cnoc na Tuppat. The Garnets are stretched and repeatedly cracked.



Huth, coll.

Fig. 2. × 1. Sheared Hornfels with drawn-out Knoten. A quarter of a mile slightly east of north of Mullach Creag Riaraidh.

elongation of the clastic grains in a siliceous schist a third of a mile to the north-east.

Certain thin greenish seams in a finely laminated hornfels, 10395, 150 yds. S.S.E. of the summit of Cnoc an t-Saic, have been found by Dr. Flett to contain pyroxene, epidote, quartz and hornblende. It is probable that they represent laminæ which were once calcareous, and that they are closely allied to the thin schistose seams containing hornblende and zoisite, which have already been mentioned many times in Chapter II.

On the north flanks of Carn Salochaidh a few patches of hornfels are found, but most of the pelitic zone consists of somewhat sheared rocks, which may be classed as phyllites, and resemble types already described near Bad a' Bhathaich, in the Kildermorie district.

Near the top of Carn Bhren the beds are vertical and strike north-east, but nevertheless they are, in places, in the condition of unsheared hornfels. The unsheared rocks include thin seams (14156) with zoisite, pyroxene and some pale green hornblende. These seams represent calcareous silts and are the non-schistose forms of the zoisite hornblende granulites of the schists.

Some small patches of pelitic or semipelitic sediment entangled in the granite in Diebidale River, rather more than two-thirds of a mile N.N.E. of Leaba Bhaltair, have been altered to an unusual degree. They show no obvious parallel arrangement but abundant large scales of brown biotite lying at different angles to one another. Dr. Flett states that specimen 11229 is coarser in grain than most hornfelses, and that the quartz and felspar form a mosaic or "*pflaster*" of water-clear recrystallised grains: fine needles of sillimanite occur in dense aggregates.* C. T. C.

The siliceous beds never show such clear evidence of thermo-metamorphism as the pelitic. At Creag Dhubh Bheag and the head of Glen Diebidale, various pelitic seams, too thin to be shown on the one-inch map, are intercalated in the siliceous series, and are full of deformed spots, even in situations two-thirds of a mile from the granite. One of these deformed spotted seams on Creag Dhubh Bheag (10437) has been examined by Dr. Flett and found to contain sillimanite. The siliceous schists in which these spotted seams occur appear to be somewhat whiter, more coarsely granular and perhaps less schistose than usual, but they show no clear signs of hornfelsing (10859 and 10860, from 1166 yds. north-east and a third of a mile slightly west of north of the Ordnance Station 2250, Diebidale Ridge). The siliceous schists close to the granite near Creag Dhubh Mhor and Creag Dhubh Bheag are nearly vertical, but have the same strike as those further away. C. T. C., C. B. C.

CARN AN LIATH-BHAID TO SOUTH SIDE OF MEALL NA H-UIGEIG.

Pelitic or semipelitic beds which still show a spotted hornlefsed character are found all along the granite margin in this district, but on Meall na h-Uigeig they make an unusually broad band, from a quarter to half a mile wide. About half a mile north of Carn an Liath-bhaid they form a detached band, separated from any visible granite by a broader belt of pelitic schist. For some distance east of the summit

* For more complete description see Chapter VI.

of Meall na h-Uigeig they are nearly horizontal, but in most localities the inclination is steeper than in the other districts described.

It is doubtful whether any beds are so free from shearing as some of those near Kildermorie and Cnoc an t-Saic, but the contrast between the schists and the patches shown on the map as hornfels is still striking, as may be seen on comparing the finely laminated spotted hornfels just east of Carn an Liath-bhaid, where the dip is north-west from 38° to 50°, with the lustrous garnetiferous mica schist, isoclinally folded along axial planes striking north-west, nearly half a mile east of this hill.

No distinct crystals of andalusite or chiastolite have been observed in this district.

In a somewhat sheared hornfels in Abhuinn a' Choire Bhuig structures have been observed which may possibly represent sun-cracks and worm-tubes.

Specimen 10952, taken as a sample of various thin greenish seams which occur in the hornfels 1030 yds. somewhat west of south of Creag na Ceapaich, was found on microscopic examination to be a garnetiferous hornblende hornfels, and probably represents a seam which was originally slightly calcareous. Other somewhat similar seams, in more sheared rocks 1000 yds. slightly west of south of Creag na Ceapaich, contain both hornblende and zoisite (10956). C. T. C.

CHAPTER VI.

PETROGRAPHY OF THE OLDER IGNEOUS ROCKS AND HORNFELSES.

PLUTONIC ROCKS.

THE pre-foliation igneous complex of Carn Chuinneag and Inchbae includes epidiorites (metamorphic augite diorites and gabbros, foliated or not), biotite gneisses (granite gneisses, often with augen structure), hornblende biotite and augite biotite gneisses (tonalite gneisses), riebeckite gneiss (paisanite gneiss), together with pegmatite gneisses and aplite gneisses or granulites.

Biotite granite gneiss.

The augen gneiss of Inchbae and Carn Chuinneag is in the greater part of its extent a coarsely crystalline, thoroughly gneissose rock with elliptical augen of pink felspar often an inch across, and smaller porphyritic crystals of quartz. The augen usually have their long axes parallel; the somewhat granulitic or gneissose matrix winds around them and contains grey quartz, pink felspars, abundant black biotite and a less amount of muscovite. The larger quartzes are milky, or have a bluish opalescence.

The large conspicuous felspars are orthoclase or microcline. In the hand specimens they have the "corded" appearance of perthitic felspar; under the microscope they prove to contain numerous albite veins. Carlsbad twinning is almost universal. The microcline structure which many of them exhibit may be partly original, but there is reason to believe that it has often developed by pressure after consolidation; it is frequently local, appearing in part of a felspar phenocryst but fading away in other portions. The inclusions are quartz in rounded grains, oligoclase in small eumorphic tablets, and less commonly biotite, muscovite, zircon, apatite. Occasionally the enclosed quartz is in graphic relation to the felspar. The large quartzes are only subhedral. Their principal inclusions are small dark rods (rutile ?) and empty cavities. The biotite in irregular scales, often clustered, has a strong pleochroism ranging from clear yellow to dark brown, nearly black, but sometimes it is greenish: it has pleochroic halos around zircon and sphene. The muscovite is in ill-defined plates often enclosing quartz: it is sometimes pale green in section with feebly pleochroic spots. Oligoclase and albite appear in all the sections, but not abundantly. Frequently small grains of vermicular micropegmatite (myrmekite) may be seen at the margins of the felspar. Of the accessory minerals, apatite, sphene, zircon and iron oxides are most common. Brown orthite (rarely eumorphic) is found in many sections, encircled by clear yellow epidote; the latter often occurs as small prisms

scattered through the other ingredients of the rock. The rarer accessories include garnet and fluor spar: the latter has been seen only at one locality (11789), near the hut on the west side of Carn Chuinneag ($\frac{5}{8}$ mile east by north of Leaba Bhaltair).

In practically all the sections, effects of crushing are very obvious. Though some of the rocks look nearly massive in the hand specimens, with the phenocrysts of felspar and quartz apparently unbroken (Plate XI., Fig. 1), they prove on microscopic inspection to be more or less crushed in the groundmass. Occasionally the matrix is completely granulitic, while the large felspars seem almost intact. As a rule the crushing has affected the rock irregularly, and bands of flaser material can be traced, though for no great distance, separating phacoids which retain much of their original structure. In all cases the matrix suffers most, a fact which establishes that the rock was thoroughly crystallised before the crushing movements ceased. The felspars have proved far more resistant to crushing than the quartz, and often have their centres unbroken while all the quartz phenocrysts are reduced to granulitic mosaics. The ease with which the matrix breaks down must be due to its heterogeneous character. Its grains of quartz, felspar and mica are usually not in perfect contact but are separated by small fissures. This is proved by the way in which staining and weathering by percolating solutions first affect their surfaces. Where the pressures are sufficiently great the grains of the matrix begin to move on one another; the larger phenocrysts being homogeneous and free from cracks are less readily broken. The grains of the matrix are carried past them. The first symptoms of breaking up in the phenocrysts are the appearance of a border of detached granules which have been dislodged by the friction of the moving granulitic matrix; they are swept away and become blended with it. Continued pressure produces cracks in the quartz, and irregular strain shadows develop in the interior of the mineral; then it breaks up rather suddenly into a mosaic which at first has the rounded shape of the quartz grain, but soon flattens out into a lenticle parallel to the foliation, and finally becomes a long granulitic streak mingled with some felspar and mica which have worked inwards from the matrix. The felspar does not break down by cracks spreading through it in the same way; it loses only by detrition at its surface, and to the last the core remains optically homogeneous. Precisely similar changes are well known to occur in grits which contain pebbles of quartz and felspar (like the Aberfoyle grits of the Southern Highlands*), and in the granite boulders that occur in conglomerate gneisses, such as the Schichallion Boulder Bed.

The minerals of the granite were all of a kind which are fairly stable under cataclastic deformation, as may be inferred from the fact that they are common ingredients of granulitic gneisses. Some development of new minerals, however, has taken place either during the crushing or at a slightly later period. Muscovite is always most abundant in the narrow crush bands; it has developed from the alkali felspar. Small grains of epidote also make their appearance with especial frequency in the crushed portions of the rock. It can only be formed at the expense of oligoclase, which is the principal lime-bearing mineral, and where this felspar is common it is often

* E. H. Cunningham Craig, 'Metamorphism in the Loch Lomond District,' *Quart. Jour. Geol. Soc.*, 1904, vol. lx. p. 16.

replaced by polysynthetic albite crystals filled with epidote granules. In other rocks there are albites full of muscovite flakes, and these may be pseudomorphs after perthitic orthoclase. Microcline structure is often developed in the orthoclase by crushing. The microcline-perthite, when granulitized, passes into an aggregate of small individuals of microcline and clear albite.

Muscovite gneisses (pegmatite gneisses, aplite gneisses).

Though muscovite is not common in the main augen gneiss, it occurs in great plenty in certain pale-coloured, usually fine-grained, granulitic gneisses which are found both within the granite and in the surrounding schists. These are sheared aplites and pegmatites. They are non-porphyritic, often well foliated, and not unfrequently contain small grains of pink garnet. Some of these rocks are so uniform in grain and so perfectly granulitic that they bear a very strong resemblance to the sedimentary gneisses (granulitic arkoses) of the Moine Series.

Hornblende biotite gneisses, pyroxene biotite gneisses (tonalite gneisses).

Very seldom a crystal of green hornblende, like that of hornblende granites, can be found in the augen gneiss. Near the north-western margin of the laccolite (for example, half a mile north of Carn Dubh and half a mile W.N.W. of Leaba Bhaltair) there are dark-coloured rocks containing green hornblende, sometimes also pale green pyroxene, much biotite and a little quartz. Fine networks of sagenite are frequent in the brown mica. Some of these rocks are well foliated gneisses, others show porphyritic felspars and quartz, and are quartz diorites or tonalites somewhat granulitised. They are finely porphyritic, do not contain the large perthitic phenocrysts which characterise the augen gneiss, and have less quartz and more plagioclase and sphene. Their polysynthetic felspar is oligoclase and albite, in large crystals full of minute prisms of epidote and zoisite (representing original felspars more rich in lime), and also in small perfectly clear rounded grains in a granulitic mosaic. The larger epidotes have sometimes brown cores of orthite. Orthoclase is not common, and microcline is very scarce in these rocks.

It is extremely probable that some of these hornblende gneisses, which occur mostly at the junctions of the acid gneiss with the dark basic rocks, have arisen from the partial absorption of gabbro fragments in the granite.

Riebeckite gneiss and ægirine riebeckite gneiss (paisanite gneiss).

This rock is a pink gneiss, well foliated, with reddish felspar, abundant quartz, and small patches of jet black riebeckite and ægirine (Plate XI., Fig. 2). It is thoroughly gneissose in character, and though it contains augen of perthitic felspar and lenticles of quartz, these are few and make little show in the hand specimens.

The mineral constitution of the rock is very simple: alkali felspar and quartz make up nearly the whole of it. The femic minerals bear only a very small proportion to the salic. The felspars are orthoclase and microcline with a little perthite, and a good deal of albite both

untwinned and polysynthetic. The riebeckite has the intense pleochroism and nearly straight extinction which are distinctive of this mineral: the ray vibrating parallel to the crystallographic axis is yellow green, the two others are blue black. The axial angle is very large: on account of the intense absorption the optical sign and optical orientation could not be made out. The ægirine ranges in pleochroism from yellow green to very dark green: it is much less abundant than the riebeckite. All the minerals are ideally fresh. Zircon in small four-sided and eight-sided prisms is unusually abundant; iron oxides are scanty, and there is a little apatite but no epidote or mica.

In structure this rock is granulitic. Except the zircon, and occasionally the ægirine, no constituent is eumorphic. Quartz and the felspars are in small, equidimensional grains without trace of crystalline faces. A few larger crystals of perthite recall the phenocrysts of the augen gneiss, but are highly irregular in form. The riebeckite forms ragged prisms and occasionally spongy poikilitic masses enclosing quartz and felspar, such as frequently occur in paisanites and comendites. The ægirine also is mostly anidiomorphic. Evidence of crushing is afforded by the granulitic lenticles of quartz, but is seldom very conspicuous. There are also small crush belts in many of the sections. It is clear that the rock has been granulitised, though probably it had originally the structure of an aplite, which is not very distant from that of a granulitic gneiss. But there seems no reason to believe that any new minerals have developed during the metamorphism. In particular we may remark on the absence of muscovite in a rock so rich in alkali felspar.

In one place Dr. Crampton obtained veins of riebeckite pegmatite, with amphibole prisms about an inch in length. Murgoci has advocated a pneumatolytic origin for this mineral,* and these pegmatites may seem to support this hypothesis, but for the mass of the rock there is nothing to favour such a view, as the riebeckite is as much a primary ingredient as the quartz and alkali felspar.

	I.	II.	III.
SiO_2	73·19	73·80	71·35
TiO_2	0·27	0·23	0·47
Al_2O_3	12·65	11·90	13·68
Fe_2O_3	1·04	1·90	1·75
FeO	1·53	1·91	0·97
MnO	0·08	0·12	0·18
(CoNi)O	nt. fd.	—	nt. fd.
CaO	0·55	0·30	1·85
BaO	nt. fd.	—	0·05
MgO	0·30	0·33	0·84
K_2O	5·08	4·93	4·36
Na_2O	4·45	5·05	3·75
Li_2O	trace	—	trace
H_2O at 105° C.	0·09	0·04	0·19
H_2O above 105° C.	0·38	0·13	0·51
P_2O_5	0·24	—	0·11
F	nt. fd.	—	—
FeS_2	0·17	—	nt. fd.
ZrO_2	—	·04	—
Total	100·02	100·68	100·06

* G. M. Murgoci, 'On the Genesis of Riebeckite and Riebeckite Rocks,' *Amer. Jour. Sci.*, 1905, vol. xx. p. 133.

I. Granite gneiss (11789), Carn Chuinneag. At the hut $\frac{5}{8}$ mile east by north of Leaba Bhaltair. (Anal. E. G. Radley).

II. Ægirine riebeckite gneiss (11017), 360 yds. N.N.E. of Ordnance Station, 2749 ft., Carn Chuinneag. (Anal. W. Pollard.) This rock contains rare earths (Ce, Th, etc., 0·04 per cent.). Possibly traces of P_2O_5 and Li_2O are also present.

III. Granite (14111), Glen Etive, Argyll. (Anal. E. G. Radley.)

A comparison of these three analysis shows that the Carn Chuinneag granite gneiss has the composition of a typical granite. Its chief peculiarity seems to be the high percentage of alkalies; probably no other British granite as yet analysed exceeds it in this respect. These analyses also prove the close similarity in composition between the biotite gneiss and the ægirine riebeckite gneiss; the latter contains slightly more silica and alkalies, and distinctly more iron oxide. It is not difficult to see why riebeckite is the ferromagnesian mineral in the one case and biotite in the other, for the riebeckite gneiss has more soda and iron (hence the presence of soda-iron pyroxenes and amphiboles), while the biotite gneiss has more potash and alumina, which are essential components of biotite and muscovite.

Gabbros, diorites and quartz diorites.

In their original condition the basic rocks included gabbros, augite diorites and quartz diorites. The gabbros consisted of greyish green diallage, mostly with a basal striation, which with twinning on the orthopinacoid yields a herring-bone structure. Their felspar was basic labradorite and contained innumerable minute black rods and plates of the type usual in schillerised plagioclase; it is sometimes zoned with borders of andesine. Ilmenite, apatite and a variable amount of biotite are the accessories; these rocks were often free from quartz and probably also from orthoclase. The structure tended to be ophitic (Plate XI., Fig. 5), as though idiomorphic pyroxene occurs, that mineral as a rule was less perfectly formed than the plagioclase, which occurs in elongated crystals often partly surrounded by the diallage. No traces of olivine have been seen in these rocks.

In the diorites and quartz diorites greyish green augite was also the prevalent femic mineral, and as a rule had not the diallage lamination. With it occurred brownish primary hornblende (often regularly grown upon the augite) and brown biotite like that of the granites. The plagioclase was nearly eumorphic, zonal, with centres of labradorite and margins of andesine and oligoclase. Whether original albite or orthoclase was present is not certain. Quartz and micropegmatite are often seen filling interstitial spaces. A few of the quartz diorites have been porphyritic, showing blebs of opalescent quartz and remains of felspar phenocrysts. The other ingredients were sphene, apatite and iron oxides.

None of the rocks of this group are in their original state; they all show effects of pressure, though in the least altered it is not difficult to infer what the rock was like before metamorphism began. The first symptoms of change are found in the pyroxene; a narrow border of green hornblende begins to form upon it, often partly in parallel growth. It has ill-defined boundaries both internal and external, with frayed edges which emit small processes into the felspar and inwards through the pyroxene. In some cases the hornblende spreads regularly through the greater part or the whole of a pyroxene grain: the centres retain the grey green colour of the augite, while the edges are deeper green hornblende. A separation of iron oxides sometimes precedes the

transformation. The paler-coloured centres of the hornblende masses can often be distinguished from augite only by a slightly greater pleochroism and by their extinguishing simultaneously with the hornblende of the periphery. At a later stage the centres also take on the darker colour of the metamorphic hornblende.

In other cases, and this is perhaps more common, after the formation of a continuous border of hornblende the central parts of the augite crystals suddenly change into clusters of anhedral prisms of amphibole. These have no definite orientation, and polarise in individual fashion (Plate X., Fig. 5).

Plagioclase felspar, the other important constituent of these rocks, is less susceptible to pressure than the augite, and retains its integrity when the latter is already partly amphibolised. But before the transformation of the augite is complete the plagioclase also is affected. Needles and short prisms of colourless clinozoisite appear in it, in small numbers at first but rapidly increasing. In some rocks they are exceedingly small, in others they are large, and this depends apparently on the amount of lime-felspar present in the original plagioclase; when that was rich in anorthite the needles are abundant and fairly large; but when it was oligoclase they are few and widely separated. Many of the crystals were zoned, with basic centres and more acid margins, and the zoisite prisms are often densely clustered in the interior of the felspar but much scarcer in its external parts. The felspar in which these zoisite prisms lie retains its polysynthetic structure but loses its turbidity and schillerisation, becoming clear and transparent. It may be andesine, oligoclase or albite. The process in fact consists of an excretion of the anorthite molecule as zoisite, while the remaining felspar approaches more and more closely to albite in composition, but the shape of the original plagioclase is fairly well preserved.

In only two slides of these rocks (12678, 12385) has garnet been observed, as small pink crystals which occur with zoisite in a matrix of clear albite. Its scarcity is in striking contrast with the abundance of this mineral in the garnetiferous epidiorites intercalated in the Moine schists. Among the changes which go on concurrently with those described the most important is the formation of sphene after ilmenite. It begins upon the surfaces and gradually spreads inwards through the patches of iron ores in the rock.

In this transformation there has been, so far as we can see, no change in the chemical composition of the mass, but the components have rearranged themselves in new combinations, which are more stable under pressure at low or moderately high temperatures than the original minerals of the igneous rocks, formed at high temperatures from a molten magma. The conversion of ilmenite, plagioclase and augite, into sphene, zoisite, albite, hornblende and quartz is very characteristic of the metamorphism of basic rocks, and may be represented by a chemical equation.* The biotite, apatite and quartz are in equilibrium under both sets of conditions. For the conversion of anorthite into zoisite additional lime is required, and this is probably furnished by the pyroxene, as lime is set free in the conversion of augite into hornblende. Some silica is liberated also, and this may account for the presence of numerous small spots of quartz in the hornblende of many of these rocks. These mineral transformations are nearly

* M. Grubenmann, 'Die krystallinen Schiefer,' 1904, vol. i. p. 36.

complete in some of the rocks before the original igneous structure is much altered. The augite may be converted into hornblende, the plagioclase into zoisite, albite and quartz, while still the ophitic relations of the femic to the salic minerals are perfectly clear. In these rocks the original skeleton networks of ilmenite, partly changed to sphene, are little distorted. The felspars retain their eumorphic shapes and are not crushed. Hence we must conclude these changes are not due to granulitic action breaking down the rock, but to increased pressure acting at comparatively low temperatures. The medium which effected the chemical exchanges between augite, felspar and ilmenite must have been the interstitial water. For that reason the changes began (in ilmenite and augite) on the surfaces of the crystals.

Before these transmutations are perfected the pressures in some cases have increased to the crushing point, and interstitial movement has set in. The result is the production of a gneissose or foliated structure, especially shown by the orientation of the hornblende prisms and the plates of biotite with their faces parallel to the schistosity. In the dioritic rocks of the intrusive complex good schists have not been so frequently produced as in the thin basic dykes of later age, which have been severely crushed along lines of special shearing.

It will be seen that in the acid rocks there is much granulitisation and cataclastic fracture and but little mineral change; in the basic rocks there is much mineral change but little granulitisation. The energy exerted by the metamorphic pressures was spent in the one case in mechanical, in the other in chemical work. The facility with which the augite and plagioclase of the gabbros and diorites were reconstructed is probably one of the chief reasons why these rocks retain their original structures so much better than the granites.

	I.	II.	III.
SiO_2	54·51	52·84	55·87
TiO_2	1·74	2·19	0·56
Al_2O_3	12·26	14·06	13·52
Fe_2O_3	1·64	1·73	2·70
FeO	7·60	8·38	5·89
MnO	0·32	0·25	0·10
(CoNi)O	0·03	0·05	—
CaO	8·80	8·72	8·87
MgO	6·89	5·55	6·51
K_2O	1·85	1·74	1·72
Na_2O	2·37	2·90	2·42
H_2O at 105° C.	0·04	0·08	0·09
H_2O above 105° C.	0·94	1·15	1·56
CO_2	0·36	—	—
P_2O_5	0·78	0·29	0·25
Cl	? trace	—	—
FeS_2	0·20	0·14	—
BaO	nt. fd.	nt. fd.	0·02
Li_2O	trace	? trace	trace
Total	100·33	100·07	100·08

I. Gabbro (biotite amphibolite), 11790, 783 yds. slightly east of north of Carn Dubh. (Anal. W. Pollard.)

II. Gabbro (biotite amphibolite), 11792, Middle Glen, south side of Diebidale River. (Anal. E. G. Radley.)

III. Gabbro, 2 miles south of Emigrant Gap, Placer County, California. (Anal. W. F. Hillebrand.) Clarke, 'Analyses of Rocks.' (*Bull. U.S. Geol. Survey*, No. 168), 1900, p. 198.

Two specimens of the basic rocks of the Carn Chuinneag laccolite have been analysed. One of them (I.) is nearly massive, contains some biotite, and shows grains of blue quartz in the hand specimen. The other is a good hornblende schist. It will be seen that though the first rock is slightly more rich in silica the differences between the two analyses are really unimportant; hence there seems no reason to believe that the quartz has been derived from the granitic veins which cut the basic masses. The third analysis is cited to show that there are gabbros of similar composition; but it is apparent that the basic types of the Carn Chuinneag complex were not, so far as has been ascertained, olivine gabbros of normal type. They belonged rather to the olivine-free gabbros, some of which contain primary quartz, like the Carrock Fell rock. This is in accordance with the absence of pseudomorphs after olivine, and the frequent presence of quartz, even in specimens which show good igneous structure. These rocks, in fact, lie on the boundary line between gabbros and augite diorites.

GARNETIFEROUS ALBITE GNEISS.

The albite gneiss that occurs in the augen gneiss on the north-west shoulder of Carn Chuinneag, and contains streaks of magnetite and tinstone, is in many ways a peculiar rock. There are two main outcrops of it, one half-way up the slope and the other near the top. Both are similar in their essential characters, but the rock is by no means uniform; in fact there is a considerable diversity of types even in so small an outcrop. In some places it contains large garnets one or two inches across, not eumorphic and filled with enclosures. In other specimens the garnets are small. The albites may form rounded spots which give the rock a nodular character (Plate XI., Fig. 3). The amount of biotite varies considerably, and the magnetite-tinstone masses may occur only as small streaks or as irregular bands several feet in length.

The minerals of which these different varieties are composed are principally albite, green biotite, quartz and garnet. The albite greatly predominates; it is fresh and clear, the larger crystals showing complicated albite and pericline twinning, but many of the smaller grains are quite simple and easily confounded with quartz. The biotite is next in importance; its most noticeable feature is the pleochroism, which ranges from clear yellow (slightly brown) to deep green. Quartz is not abundant in any of the specimens; the garnets are pale pink, never idiomorphic, and, especially when large, are full of biotite, quartz and other inclusions.

Orthoclase and microcline are very seldom visible in the slides; muscovite is absent; the principal accessories are apatite and zircon. Many specimens of the rock contain little or no magnetite, but when that mineral does occur it forms considerable areas. There is also in all the specimens a certain amount of carbonates, usually clear and transparent (calcite and dolomite) but often rusty brown from the presence of iron. The carbonate may occur as small rhombohedra in the albite, but more commonly forms irregular groups lying between the other ingredients. It is apparently primary, and not a product

of decomposition or infiltration subsequent to the recrystallisation of the rock.

Except where mica is especially abundant, the rocks are not schists; they have rather the texture of gneisses. The albites tend to develop as large rounded crystals, comparatively free from enclosures. They form white spots in the hand specimens and clear patches in the slides. There is no tendency to crystalline outlines in this mineral more than in any of the others.

These larger albites are encircled by the matrix, which consists of biotite, albite and quartz (Plate XI. Fig. 3). There is no very obvious parallel arrangement of the micas. Cataclastic structures and strain phenomena are rare, all the minerals having evidently recrystallised freely after the deformation.

The following analysis of the garnetiferous albite gneiss (11796) from the upper stanniferous belt on the north-west shoulder of Carn Chuinneag has been prepared by Dr. Pollard:—

SiO_2	54·89
TiO_2	0·38
Al_2O_3	16·54
Fe_2O_3	1·85
FeO	12·30
MnO	0·84
(CoNi)O	0·02
CaO	1·08
BaO	nt. fd.
MgO	1·52
K_2O	2·35
Na_2O	5·39
Li_2O	trace
H_2O at 105° C.	0·11
H_2O above 105° C.	2·29
S	0·02
P_2O_5	0·07
CO_2	0·42
Total	100·07

Dr. Pollard reports that "tinstone was looked for but not found. The figures for FeO were obtained by the sealed tube method, and (as there is a little sulphur present in the rock) are probably a little too high. So much time was required to decompose the rock by HF (apparently owing to the garnets) that there was great risk of partial oxidation. The highest estimation by the HF method gave FeO=11·86 per cent."

The magnetite-tinstone streaks that occur in the garnetiferous albite gneiss consist mostly of granular magnetite without crystalline form. They may contain 86 per cent. of iron oxides. The distribution of the cassiterite is best studied in microscopic sections (Plate XI. Fig. 4.) It is not disseminated evenly through the iron oxides, but may be absent from considerable areas, and, when it does occur, forms patches or nodules composed of small brown crystals, many of which have rudimentary crystalline forms. Most of them are nearly equidimensional, but a few are elongated rod-like prisms. In cross sections tetragonal and octagonal forms are often seen, but the faces are

usually ill developed. The usual cleavage of tinstone is visible, and the mineral is zoned; at the centre it is often dark and turbid with small black enclosures, while the outer parts of the crystals are often transparent and colourless or pale yellow. A feeble pleochroism can usually be detected. The black enclosures are probably magnetite, and well defined octahedra are often found in the centre of groups of cassiterite crystals. A subradiate, almost stellate arrangement of prismatic crystals of tinstone may be observed in some of these aggregates.

The magnetite-tinstone masses contain a variable amount of impurities. A mineral which has the optical properties of apatite occurs sometimes; the other ingredients are quartz, albite and green mica, which are the components of the garnetiferous albite gneiss. Garnet has not been seen in any of the magnetite blocks. These accessory minerals may form only a very small proportion of the whole mass, as in the specimen analysed, where they are about ten per cent.; in others they amount to about one-half, while at the other extreme there are garnetiferous albite gneisses with five to ten per cent. of iron oxides. As a rule, however, the transition from the ore-bodies to the gneiss is a rapid one, and the boundaries are sharply defined in the hand specimens.

One of the magnetite blocks (11233) from a point 1100 yds. slightly south by east of the Ordnance Station 1692, Mullach Creag Riaraidh, was analysed by Dr. Pollard with the following result:—

SiO_2	7·97
Al_2O_2	0·98
Fe_2O_3	60·69
FeO	25·94
MnO	0·16
CaO	0·59
MgO	0·26
SnO_2	3·22
H_2O at 105°	0·06
H_2O on ignition..	0·43
Total	100·30

The alkalies were not estimated.

Four other specimens were tested for oxide of tin and yielded respectively—

	A	B	C	D
SnO_2	1·10	nt. fd.	15·78	0·24 per cent.

These results indicate that the percentage of tin in the ore varies greatly.

Genesis of the Tin Ore.

It cannot be said that either the field work or the microscopic and chemical investigations have enabled us to reach a satisfactory solution of this question. As both the albite gneiss and the magnetite-cassiterite masses are of exceptional character, and nothing similar has been met with either in this Sheet or in any other district of Moine rocks, we probably shall not err in assuming that in their origin they

are closely related. It seems also established that neither of them is connected with the Newer Granite intrusions or the basic dykes, since one of the latter cuts the stanniferous bands on the north-west shoulder of Carn Chuinneag.

In some respects the albite gneiss is not unlike certain of the Moine gneisses (paragneisses). Many of these contain garnets and spots of albite, though never in the same quantity as the albite gneisses. Among the conglomerate-schists there are a few which have a matrix full of iron oxides, but no cassiterite has been found in them. On the other hand, the chemical analysis of the albite gneiss is very peculiar, and can hardly be interpreted as that of any common type of sediment. It might also be expected that if the albite gneiss is of sedimentary origin, something like it should have been found elsewhere in the Moine rocks, and especially within the aureole of the augen gneiss. Moreover, there are many inclusions of paragneiss and hornfels in the Carn Chuinneag mass, and none of these resemble the garnetiferous albite gneiss.

Again we might argue that the stanniferous gneiss is a foliated and recrystallised system of veins. It cannot be regarded as identical with the usual type of Cornish tin-vein, for quartz and tourmaline have not been found in association with the tin ore, and in fact the albite gneiss contains less silica than the country rock. But cassiterite is also found in pegmatites, which sometimes contain little or no tourmaline. The augen gneiss of Carn Chuinneag occasionally contains fluor spar, and in it there are pegmatites, not unlike some of the albite gneiss, though not stanniferous. To none of these considerations, however, can we attach much weight, especially seeing that the chemical analysis shows that the rock, if igneous, can only have been a very peculiar type of syenite.

It is also possible that the ore deposit is due to the metasomatic alteration of the augen gneiss along lines of fissure, together with the introduction of iron oxide and cassiterite. Veins of this type have been described by MacAlister from the east side of Dartmoor.* In this case also the absence of tourmaline is a difficulty. A comparison of the analyses of the augen gneiss with that of the stanniferous gneiss shows that on this hypothesis there must have been an abstraction of silica, which is so unusual that it debars us from regarding this explanation as satisfactory.

These problematical rocks might also be basic segregations in the augen gneiss, and this hypothesis was advanced provisionally by Mr. Clough and Dr. Flett † in 1903, and is accepted by Thomas and MacAlister,‡ who are familiar with the rocks. The dark colour and basic character of the albite gneiss, and its occurrence well within the boundaries of the granite, are in favour of this theory, but magnetite-cassiterite segregations have nowhere been described in granite masses. Recently Professor Vogt§ has ascertained that the granite of the Lofoten Islands contains segregations of magnetite (sometimes with garnet), and he believes that at other places, such as Gellivara, the same

* D. A. MacAlister, 'Note on the Association of Cassiterite and Specular Iron in the Lodes of Dartmoor,' *Geol. Mag.*, 1909, p. 402.

† *Summary of Progress of the Geological Survey* for 1903, p. 58.

‡ 'The Geology of Ore Deposits,' 1909, p. 56.

§ J. H. L. Vogt, 'Ueber magmatische Ausscheidungen von Eisenerz in Granit,' *Zeits. Prakt. Geol.*, 1907, vol. xv. p. 86.

phenomenon occurs. It is important to observe, however, that at neither of these localities has cassiterite been found.

SILLS AND DYKES OF EPIDIORITE, ETC.

It has been indicated on a previous page that two groups of these rocks can be recognised, namely those which are intruded into the plutonic rocks and those which are intercalated in the schists. It will be convenient to consider the second group first, because they belong to a series which has representatives in many parts of the wide area occupied by the Moine schists, and, though presenting minor variations, have a uniformity of character by no means difficult to identify.

Epidiorite Bands in the Moine Schists.

These rocks are always thoroughly metamorphic, and never show remains of igneous structures, but are typical amphibolites, though often not very schistose. Their main constituents are hornblende and felspar; the hornblende occurs in short parallel prisms, while the felspars are granular and lie between them. Hence the rocks are fissile, but they are not usually banded, as the hornblende and the felspar have not segregated into distinct folia, and some of the finer-grained specimens are fairly massive (Plate X. Fig. 3).

Though originally dolerites or olivine dolerites they contain neither olivine nor augite, and, unlike the basic rocks of the Carn Chuinneag complex, they seldom show pseudomorphs after pyroxene. Their hornblende, nearly black in the hand specimen, is green or brown in the microscopic slides and strongly pleochroic in most sections, though the colour of light vibrating parallel to the *b* and *c* axes often differs little. Biotite occurs in many of them, but not in all, and may be as abundant as hornblende. It is of yellow brown to reddish brown colour and most intensely pleochroic, so that rays vibrating parallel to the cleavage are almost completely absorbed. Networks of rutile needles, so common in the biotite of the gneisses, have not been observed in these schists. Epidote is a frequent accessory, sometimes yellow with strong double refraction, at other times colourless (clinozoisite or zoisite). Pink garnet occurs in some amphibolites in crystals which may be large and poikilitic, but are sometimes small and free from enclosures. Quartz is nearly invariably present, often in fair quantity. Apatite, iron oxides and pyrites are universal; brownish sphene may replace the ilmenite or titaniferous magnetite partly or completely. A small amount of muscovite may very generally be found, usually embedded in felspar, but it is never conspicuous. Rutile also is often present.

All the principal minerals are anhedral, and the structure is of the "granoblastic" type. Occasionally an amphibole crystal in cross section has boundaries which indicate prism faces, and the biotite and muscovite scales may have their basal planes defined. The felspar and quartz are always in grains forming a mosaic. Only the little prisms of epidote, the smallest garnets, rutile and apatite can be found with a moderately good crystalline development. The larger garnets are pseudoporphyritic, but the dominant feature of the rock structure

is the parallel orientation of the hornblende prisms and tablets of biotite which produces the schistosity.

The felspars of these amphibolites are not all of one kind, though in each specimen only one variety of felspar is present as a rule. Some of them contain labradorite or andesine in irregular, polysynthetic grains, perfectly clear and evidently recrystallised. These rocks are never garnetiferous, have seldom any epidote or zoisite, though not rarely small borders of sphene surround the iron ores. In most of them, however, the only felspar is albite, having lower refractive indices than quartz and Canada balsam, and usually forming rounded untwinned grains not easily distinguished from quartz except by cleavage and weathering. In the rocks of this class there is often much epidote and zoisite, and hence we infer that the original basic soda-lime felspar has passed through the same transformation as in the gabbros and diorites of the plutonic complex already described. But other rocks having only albite felspar are distinctly poor in epidote; these, however, often contain much sphene, and some biotite and muscovite. Anorthite, albite and augite have recrystallised to form sphene, white mica, biotite and hornblende. In the garnetiferous epidiorites albite is nearly always the only felspar. The anorthite, once present in the plagioclase, has with augite yielded garnet. It is interesting to recall that on fusing garnet we obtain a mixture of silicates in which anorthite, augite and olivine predominate. The change, consequently, is of a reversible type; garnet, which is characteristic of the schists, being produced at low temperatures, while anorthite, augite and olivine, minerals of the igneous rocks, are obtained from igneous fusion.

The calc-biotite schists that occur at the margin of some epidiorites (Plate X. Fig. 4) are coal-black rocks with white specks of carbonates, and have a brilliant lustre on the cleavage surfaces from the abundance of black mica. They are perfect schists, and consist mainly of plates of biotite, very fresh and highly pleochroic, with grains of white calcite (readily soluble in weak acid) and usually a fair amount of yellow epidote and quartz. Other components are few, but include iron oxides and sphene, often rather abundant; felspar is scarce in the rocks from Bodach Mor, but is fairly abundant in specimens from 350 yds. north of the outlet of Lochan Pollaig, where a little hornblende and large garnets occur in the biotite schist. The felspar is always untwinned, and is presumably albite.

The Basic Dykes in the Carn Chuinneag Complex.

The dark rocks that form dykes cutting the augen gneiss and often occupy zones of secondary shearing have been completely transformed into amphibolites or hornblende schists. Though consisting essentially of the same minerals as the epidiorite bands that occur in the Moine schists, they present several distinctive features. They are generally finer-grained, presumably because, being narrow dykes, they were rapidly cooled.

Their minerals are green hornblende, biotite, felspar, quartz and iron oxides, with small amounts of sphene, apatite, epidote and zoisite. The hornblende has never the brown colour sometimes seen in the epidiorites previously described. Biotite is rather plentiful, and felspar also is abundant. It is commonly albite in irregular grains

or in polysynthetic crystals filled with small prisms of epidote. Calcite is present, apparently in place of epidote in some dykes. No garnet was seen in these rocks, but often they contain much sphene. Quartz is rather common, especially when albite is the only felspar present.

A dyke a little above a steep rock pinnacle on the south side of Glen Diebidale has been analysed. It is a fine-grained hornblende schist or biotite amphibolite (Plate X. Fig. 6), and shows no remains of igneous structures. Hornblende in short anhedral prisms, biotite in brown plates, granular quartz and felspar are its chief components. There is also a small amount of calcite in the rock. In the specimen analysed (12680) the felspar is practically all albite, mostly untwinned, though a few grains have refractive indices which indicate that they are oligoclase. The rock contains no garnet and very little zoisite or sphene. In structure it is almost as completely metamorphic as the Moine epidiorites.

	I.	II.
SiO_2	47·36	45·24
TiO_2	2·02	2·26
Al_2O_3	12·47	15·63
Fe_2O_3	2·64	5·56
FeO	10·03	7·19
MnO	0·14	0·23
(CoNi)O	0·07	trace
CaO	9·70	9·38
MgO	6·97	7·82
BaO	nt. fd.	—
SrO	nt. fd.	—
Li_2O	trace	—
K_2O	1·08	0·72
Na_2O	2·50	2·01
H_2O at 105° C.	0·10	1·12
H_2O above 105° C.	1·59	2·21
P_2O_5	0·30	0·20
CO_2	3·21	0·49
S	nt. fd.	—
Total	100·18	100·06

I. Biotite amphibolite (12680), dyke in shear-zone above the rock pinnacle on south side of Glen Diebidale, nearly a mile S.S.W. of Mullach Creag Riaraidh. (Anal. E. G. Radley.)

II. Olivine dolerite (7854) sill forming summit of Ben Lee, north-west of Loch Sligachan, Skye. (Anal. W. Pollard.) A. Harker, "Igneous Rocks of Skye," *Mem. Geol. Survey*, 1904, p. 248.

A comparison of these two analyses shows that among the Tertiary olivine dolerites of the West of Scotland there are rocks which in their chemical composition are almost identical with the biotite hornblende schists which form dykes in the crush zones of the Carn Chuinneag granite gneiss.

The Aureole of the Carn Chuinneag Plutonic Complex.

In the belt that encircles the augen gneiss, representatives of all the Moine schists (mica schists, quartz schists, granulitic gneisses, zoisite gneisses) may be found which show extreme metamorphism, and differ very little from the rocks of the same class occurring in

other parts of the Sheet. Recrystallisation, development of new minerals and of foliation, have proceeded in these exactly as in the rocks which there is no reason to suspect have been contact-altered by the granitic intrusion; if any changes of thermal metamorphism had been induced in them, they have disappeared during the epoch of movement, and the only alterations now recognisable are of a "regional" type. But there are other rocks, as described in previous chapters, which exhibit only thermal metamorphism, and are identical with contact-altered rocks from regions where extensive crustal movements have not taken place. They are hornfelses, containing minerals such as sillimanite, andalusite and chiastolite, that do not occur in the surrounding mica schists, and are proof of contact-alteration. The original structures of these rocks are far less modified than in the schists. They show the original lamination or bedding, for example, singularly well (Plate IX. Figs. 1, 2). Where the hornfelses have been involved in folding, and interstitial movement has been set up, they pass by gradual transitions into schists of the types normal in this district, and the methods and stages of the process are traceable in microscopic sections and in the field. Within short distances we can follow the passage of a bedded hornfels into a mica schist; the manufacture of schists, which in other districts requires miles for its accomplishment, is here completed in yards, and the identity of the beds in different stages of metamorphism can be established beyond question. Moreover, the agencies at work—viz., pressure and movement—are never in doubt. Since, in the enormous area over which the Moines are spread, they have never been found retaining their original structures as they do within the aureole of the Carn Chuinneag augen gneiss, these phenomena are as unusual as they are instructive.

Semipelitic and pelitic rocks prevail within the aureole, as the laccolite apparently has been intruded along a great series of shales, like those which in other districts yield the extensive belts of mica schist and micaceous gneiss so important in the Moine series. These rocks, by their nature, show contact-alteration and the formation of schists especially clearly. The sandstones and arkoses, on the other hand, that produce the quartz schists and quartzofelspathic granulites, do not, as a rule, exhibit contact-alteration in any marked way, and when they recrystallise as metamorphic rocks they pass through no very conspicuous changes in mineral composition. The calcareous shales which yield the zoisite hornblende gneisses and granulites, also occur within the aureole and are represented by calc-silicate hornfelses. The features shown by the basic intrusions are entirely those of progressive regional metamorphism, as no diabase hornfelses have been met with in this Sheet.

THE HORNFELSES.

The fine biotite hornfelses, intensely contact-altered but perfectly retaining the original lamination and unaffected by movement and regional metamorphism, are well exposed on the Garbh Allt (see Fig. 10), about one mile south-east of Glencalvie Lodge. At this locality they are greyish rocks minutely spotted and crossed by

alternate paler and darker bands about one-twentieth of an inch in breadth (Plate IX. Fig. 2). These bands are laminæ of deposit. Those which are of lighter colour consist mainly of quartz and are coarser-grained than the others ; they are layers of fine sandy sediment. The darker bands are more micaceous, and were originally fine seams of mud or shale. The banding, as seen in the hand specimens or in the bare rock exposures in the bed of the stream, is very straight and parallel, never crumpled or contorted. It is difficult to believe that this rock possessed any cleavage before it was hornfelsed, and no trace of augen structure, phacoids or strain-slip cleavage can be found in the microscopic sections. All the evidence leads to the conclusion that it was a fine greyish arenaceous shale at the time when the granite was intruded.

The microscope shows that the principal minerals of this rock are quartz, alkali felspar, garnet and biotite. The dark argillaceous seams are exceedingly fine-grained ; most of the ingredients are not over 0·01 millimetre in diameter. The biotite is reddish brown, and some of its small tablets have hexagonal basal sections. The quartz and felspar form a mosaic of particles so minute that their optical characters cannot be exactly determined, but that there is a good deal of felspar in this part of the rock is clear from the rapidity with which white mica develops when shearing begins. The arenaceous seams contain the same minerals but in larger crystals (Plate IX. Fig. 1). There is less biotite, more quartz and felspar ; the particles are often 0·05 millimetre in diameter, and the untwinned alkali felspar can be told from the quartz by its weaker refraction, cleavage and weathering. The quartz grains are subangular rather than rounded, and have often irregular outlines, as if partly corroded. The felspar tends to envelop the quartz, and is clearly recrystallised or developed during the thermal action of the granite. It is orthoclase or albite, and shows no polysynthetic structure. The minute specks of biotite are sprinkled irregularly through the other minerals, occurring both within them and between them, but principally in the felspar and the fine quartzofelspathic mosaic which forms a matrix for the quartz grains, no doubt because this represents interstitial argillaceous cement, from which by recrystallisation quartz, felspar and biotite would naturally arise.

The garnets are very small, not over 0·1 millimetre in diameter, pale pink in thin section, with enclosures of quartz, iron oxides, etc., especially numerous near their centres. They are on the whole eumorphic, most of the sections being six-sided, but many of the crystals are imperfect on one or more sides. They are far most abundant and have the most perfect shapes in the argillaceous seams ; in the arenaceous they are larger, but less numerous, have very irregular outlines, and are honeycombed with large enclosures of quartz and other minerals. This is no doubt a consequence of the resistance offered to their crystallisation by the comparatively large grains of quartz and felspar.

The less abundant minerals include muscovite, in transparent flakes, by no means common. Yellow prisms and twins of rutile are frequent, but always of very minute size. Dark iron oxides appear as plates which are six-sided, and when very thin some of them are transparent and dark brown. Sillimanite has not been observed

in this rock; the absence of cordierite is rather remarkable. An analysis of this hornfels appears on p. 112.

Many specimens of fine-banded, unsheared hornfelses have been collected from other places in the vicinity of the margin of the granite. They have essentially the same composition and structure as the rock above described, but there are variations which are of interest.

The sedimentary banding is one of the most constant features. In some rocks it is comparatively coarse, and the arenaceous layers contain pebbles 0·5 millimetre in diameter, lying in a fine biotite hornfels matrix which was originally a shale. In others the stripes are exceedingly narrow and correspondingly numerous. In the typical biotite hornfelses the micas have no parallelism, but still the rocks are somewhat fissile, as they tend to split along the banding. The laminæ may be curved; sometimes they are faulted, and they often tail-out like the quartzose bands in a sandy shale; they are not crumpled, and there are no signs of cleavage. A distinct though fine spotting, similar to that which is so constant in argillaceous rocks near an intrusive granite, is very common in these hornfelses when quite undeformed. The spots are usually spherical, and about one twentieth of an inch in diameter; they are most frequent in the finest and most argillaceous types, as the presence of quartz grains seems to interfere with their development. In many cases the argillaceous laminæ are distinctly spotted, while the alternating arenaceous bands show no spotting. Although the larger contact-minerals, such as garnet and andalusite, may occur in these spots, they seem to have no inseparable connection with them, and the spots are not stages in the crystallisation of these minerals. Usually the spots are of paler colour than the rest of the rock, and their boundaries are so ill-defined that the spotting is more easily seen with a hand lens than with the microscope. These pale spots are very fine-grained, and consist essentially of minute scales of white mica which have no definite arrangement. Other rocks have dark spots rich in biotite. Less commonly the spots are zoned, some having a white centre, mostly muscovite, and a dark border full of biotite. In the coarser hornfelses that seem to have undergone the greatest contact-alteration, rudely circular patches of quartz and biotite may occur in a more argillaceous matrix.

Garnet is practically always present in the hornfelses, but its crystals are so small that they are not easily recognised in the hand specimens. In some, however, the garnets are over one quarter of an inch in diameter, and stand out as rounded lumps on the weathered surface of the rock. The matrix of these rocks is more coarsely crystalline than usual, and this indicates extreme thermal metamorphism. The large garnets are nearly but not quite eumorphic, their faces being rough. A specimen of a coarsely garnetiferous hornfels which Dr. Crampton obtained *in situ* in the bed of the river west of Kildermorie Lodge contains acicular prisms of green hornblende in the matrix, in much less abundance than biotite. The large garnets are filled with spots of quartz, small brown prisms of rutile and grains of iron oxides. They contain hardly any biotite, but around them there is a dark zone in which this mineral is especially abundant. Evidently, in crystallising, the garnet has been able to cast out the biotite, though growing in a rock which was quite solid. We are reminded of the growth of cubes of pyrites in slates, and selenite in clays.

Hornblende is not often met with in the fine hornfelses, but in addition to the rock above mentioned two others contain it. Both have small, irregular garnets. In one specimen (10952) from 1030 yards south of Creag na Ceapaich, biotite is absent, but small grains of pale green hornblende are frequent. They are anhedral, and there is nothing to prove that they are secondary after pyroxene. The other rock contains a little biotite and not much green hornblende. It is specially interesting from the abundance of finely granular zoisite, which shows that this represents, within the aureole, the marl bands which give rise to the zoisite hornblende gneisses. In this rock (10395) there are also many small grains of almost colourless pyroxene; the hornblende is mostly fibrous, and seems to be forming from the augite. This is the only pyroxene hornfels found in the whole aureole, and the only sediment of the Moine Series at present known to contain pyroxene. It was mapped by Mr. Clough 150 yds. S.S.E. of Cnoc nan Sac.

In the more intensely altered hornfelses sillimanite is common. It occurs only in very small needles, densely clustered and embedded in quartz, felspar or biotite, and is principally found in the fine argillaceous bands where biotite also is frequent. It is always prismatic, but does not form long streams of jointed needles; the crystals show no parallelism, but point in all directions; where very small they cannot always be identified with certainty, but the larger prisms have the cross section and the optical properties which belong to this mineral. In the sheared or foliated hornfelses it is never found, and the evidence here, as in all the Scottish Highlands, is that sillimanite is a purely thermal product, a typical contact-mineral.

In one very interesting rock (11229), an enclosure of sedimentary character in the granite gneiss, which Mr. Clough obtained two-thirds of a mile N.N.E. of Leaba Bhaltair, there is much sillimanite, but it is entirely confined to small angular greenish patches which are clearly pseudomorphs after some primary mineral. These patches consist of chlorite and white mica; from their composition and the abundance of sillimanite in them it may fairly be deduced that they are pinite after cordierite. No fresh cordierite has been found in the rocks of the aureole, and seeing that the andalusite, which is far more resistant to weathering, is always represented by alteration products, we can hardly expect to obtain cordierite in a fresh condition.

This specimen has large flakes of yellow brown biotite, and grains of quartz and felspar. It is the most coarsely crystalline hornfels which we have obtained in the district, and the entire lack of orientation in its minerals shows that it has escaped or successfully resisted the dynamic metamorphism. The mosaic structure (pavement structure) so typical of altered sediments from the inner portions of granite aureoles is exceedingly well shown. The only other occurrences of cordierite and sillimanite in Moine rocks, with which we are acquainted, are at Netherly, near Rothes, where cordierite sillimanite gneiss has been found in contact with a mass of Newer diorite by Mr. Hinxman,* and in the schist adjacent to the granite of the Ross of Mull.†

* 'The Geology of Lower Strathspey,' *Mem. Geol. Survey*, 1902, p. 53.

† T. O. Bosworth, 'Metamorphism round the Ross of Mull Granite,' *Quart. Jour. Geol. Soc.*, 1910, vol. lxvi. p. 376.

Pseudomorphs after andalusite are visible in a number of rocks from the aureole (see pp. 79, 80), though this mineral is less frequent than sillimanite, and is represented only by alteration products. Three miles south-east of Lochan a' Chairn Mr. Clough obtained some particularly interesting fragments of chiastolite hornfels. These were not observed *in situ*, but very probably they were derived from near Loch a' Chaoruinn (see p. 79). In the black lustrous matrix there are white needles which have the rhomboidal transverse sections and dark cross-shaped enclosures which are usual in chiastolite (Plate IX. Fig. 5). Around them there is a very narrow black border of iron oxides or graphitic matter. The matrix shows the lamination of original bedding, as well as small subhedral garnets and black spots of angular form, rich in small brown flakes of biotite. The chiastolites have a narrow white outer rim of fine scaly muscovite, but all their central parts are transformed into brush-like aggregates of small prisms of colourless kyanite. The bedding is so well preserved, and the shape of the chiastolites is so perfect, that there is no reason to believe the rock has experienced interstitial movement or shearing. Of the three silicates of alumina (sillimanite, andalusite, kyanite), the last named has the highest specific gravity, and, according to the principle enunciated by Loewinson-Lessing * (and elaborated by Becke,† Van Hise ‡ and others), should be expected to form in place of the others in rocks subjected to intense pressures at comparatively low temperatures. As a matter of fact, the andalusite of the Carn Chuinneag hornfelses very often is replaced by undoubted pseudomorphs of fibrous kyanite. The sillimanite disappears altogether under pressure metamorphism. Kyanite never occurs in the hornfelses in bladed prisms, which might be regarded as primary, but only in brush-shaped clusters or tangled masses of small crystals forming pseudomorphs after andalusite.

The most striking examples of andalusite hornfels were obtained by Mr. Anderson a quarter of a mile from the summit of Carn Loch nan Amhaichean. In all these rocks the andalusite has been completely replaced by fine white mica and kyanite, and these aggregates stand out on weathered surfaces in prominent knobs, which may be half an inch in length. Often they retain the prismatic shapes of andalusite, but when there has been some shearing they become lenticular and lose their idiomorphism. The formation of white mica after andalusite is a well-known secondary process, and probably requires the presence of small amounts of alkalies set free by kaolinisation of the felspars in the matrix. In other circumstances, as will be shown later, it is a metamorphic change induced by dynamo-metamorphism.

EFFECTS OF SHEARING AND DYNAMO-METAMORPHISM ON THE ROCKS OF THE AUREOLE.

The contact-altered semipelitic rocks within the aureole of the Carn Chuinneag augen gneiss, when affected by regional metamorphism,

* 'Studien über Eruptivgesteine,' 1899, p. 327.

† F. Becke, 'Ueber Mineralbestand und Struktur der kristallinischen Schiefer,' *Comptes Rendus Congrès Géol. Internat., Vienna*, 1903, p. 558.

‡ C. R. Van Hise, 'A Treatise on Metamorphism,' 1904.

have acquired the characters of more or less perfect schists. Two stages may be recognised, an intermediate one in which the rock, while no longer a hornfels, is not yet a complete schist, and a final stage in which the metamorphic texture is well developed, and typical schists are the result (Plate IX. Figs. 3 and 4). The latter differ in no essential respect from the normal Moine schists outside the aureole. In the intermediate stage the distinctive nature of the rocks is very obvious. They are full of minute plates of muscovite and biotite which have a parallel orientation. These rocks in consequence are more fissile than the hornfelses, and split along planes of foliation as well as along planes of bedding. Their split surfaces are speckled with minute scales of black and white mica; hence they may be called stippled schists or speckled schists (Plate IX. Fig. 3). As compared with the mica schists and pelitic gneisses they are less perfectly foliated, and also less coarsely crystalline.

In the transformation of the banded hornfelses into mica schists three kinds of change have gone on concurrently: (1) substitution of new minerals for the previous ones; (2) growth of the crystals to larger dimensions; (3) development of new structures (foliation, etc.), with partial or complete obliteration of the old ones (sedimentary banding, knotting, etc.). These changes, however, are not radical but only partial, as (1) a considerable portion of the minerals of the schist are the same as those of the hornfels though their crystals have been enlarged, *e.g.*, garnet, muscovite, biotite and quartz; (2) though the foliation may develop either along or across the original bedding planes, it hardly ever obliterates them.

The first symptom of pressure alteration that can be detected in microscopic sections of the hornfels is the appearance of a cloud of infinitesimal flakes of white mica, especially in the fine argillaceous bands. In the hornfelses which are quite unsheared these bands have a very fine transparent mosaic-like groundmass, which may be assumed to consist of quartz and alkali felspar, though the minerals are not recognisable because of their minuteness. Under pressure the felspar splits into muscovite and quartz, and newly generated scaly mica begins to fill the clear mosaic, much as in some chemical operations a white cloud gradually forms in a transparent liquid. The same change may take place (and can be seen in weathered hornfelses) by atmospheric decomposition, but in the rocks now under description the new mica has a well-marked parallel orientation, which is the hallmark of pressure. In polarised light the sections have a shimmering aspect from the bright colours given by the scales of muscovite. The orientation of the biotite may show no distinct parallelism, and the other minerals (garnet, sillimanite, etc.) and the arenaceous bands are at first quite unaffected.

The disappearance of the felspar (presumably orthoclase) in these rocks, and its replacement by muscovite and quartz, while in the quartzofelspathic sedimentary granulites the felspar persists in the last stages of metamorphism and must have been continuously crystallising, is an interesting problem. In the augen gneiss also the felspar remains, and muscovite appears only locally in any quantity. Possibly this depends on the relation of the alkalies to alumina; in the igneous gneisses they are in approximately equal molecular proportions, but in the hornfelses and semipelitic schists the alkalies are about one-half

of the alumina. In the argillaceous rocks muscovite forms : in the less aluminous and more alkaline rocks felspar maintains its place. Two-thirds of the potash of the orthoclase is set free by the transformation of that mineral into muscovite and quartz; it is not removed in solution, but remains to take part in important mineral changes. One of these is the conversion of andalusite and sillimanite to white mica. It is not possible, however, that all the potash can be absorbed in this way, and some combines with magnesia, alumina and iron to form biotite. The femic materials required are furnished by the garnet and iron oxides, and consequently there is, with increasing metamorphism up to a certain point, a diminution in the amount of garnet visible in these rocks.

Although it is possible that some of the white mica is soda mica or paragonite, formed from soda felspar, this transformation does not seem to be so readily effected as that of potash felspar into muscovite. Albite, in fact, is quite stable under the metamorphic processes, and though not discernible in the fine hornfelses becomes so in the schists ; in some of these it forms large micropoikilitic crystals. Orthoclase, on the other hand, has not been identified as a constituent of the mica schists, and microcline has not been seen in any of them.

After the first fine micas have appeared in the groundmass mosaic, their increase in size with continued pressure is rapid (Plate IX. Figs. 2, 3, 4). According to a well-known law of physical chemistry, the smaller grains are dissolved, and their substance is deposited on the larger ones. This process is very rapid at first when the particles are very close together, as the distance through which diffusion takes place is infinitesimal. The minute size of the grains also makes their surface very great in proportion to their mass, and increases their solubility. In nearly all the other constituents solution and deposition go on ; the biotites get rapidly larger and less numerous, and the quartz mosaic becomes coarser. Albite now begins to appear mixed with the quartz in the micaceous folia, and sometimes shows a tendency to form particularly large porphyroblastic crystals. Even the finely divided iron oxides increase in size. There seems to be a diminution in the amount of rutile observable in the slides, though no quantitative measurements can be made. It cannot be transformed into sphene, as there is too little lime in the rock, and there is a possibility that it is partly absorbed in the new biotite. This latter mineral must undergo a transformation throughout, as the biotite of the schists has a more yellow-brown, less reddish-brown colour than that of the hornfels, yet there is no zonal structure, and a nucleus of "thermal" biotite cannot be found in the larger plates of new biotite.

The regenerative processes affect also the garnets : they are fewer and larger in the schists than in the hornfelses. In part they are converted into biotite, but there must also be a solution of the smaller crystals and a growth of the larger ones. The stages of the change, however, are not easily followed with the microscope ; only the results seem fairly clear. The new garnets, especially in their outer zones, contain fewer dark enclosures than the little garnets of the hornfels, but these enclosures are individually larger. They also contain more quartz, and far less frequently have idiomorphic outlines. Through the whole of this process of recrystallisation a well-marked orientation is maintained, and the rock is becoming more and more

of a schist. The foliation which so rapidly becomes the most pronounced feature of the mass is principally due to the micas. This may partly be explained by a rotation of the old irregularly scattered plates of mica in the hornfels, so as to have their long axes directed along the axis of least pressure. More probably the dominant cause is the deposit of new mica mainly on the edges of the crystals where pressure is least, and to a less extent on the faces where the greatest pressure acts. Many years ago Sorby directed attention to the importance of this as a factor in the development of slaty cleavage,* and under the name of "Riecke's law" it has recently been brought into prominence by Becke† and Grubenmann.‡ Hence the foliation of the mica schist is partly a *Krystallisation Schieferung*. This law seems to explain well the flattened shapes of the micas, but it is to be remembered that for these minerals tabular forms are habitual.

The quartz and felspar in these rocks are lenticular sometimes, but often nearly equidimensional, and Riecke's principle does not seem greatly to affect their growth. The garnets, also, are rarely of elongated form, even though they have certainly enlarged under the same conditions of pressure as the micas, and the large albites which lie in the micaceous films are never platy. From this we see that this tendency does not overcome the molecular affinities of the mineral particles and the conditions of least surface energy which determine the usual habits and forms of their crystals.

At the same time interstitial movement is taking place, and this is probably facilitated by the recrystallisation. We have seen that mineral reconstruction may go on under pressure without evidence of internal distortion of the minerals. In the chiastolite hornfels the shape of the elongated needles of chiastolite is perfectly retained, while their substance has been changed to muscovite and kyanite. In the gabbros the ophitic structure may remain when all the augite has passed into aggregates of hornblende. Whether this indicates static pressure as opposed to stress or unilateral pressure we shall not discuss here: it is sufficient to show that pressure has produced mineral change without foliation or schistosity. There can be no doubt that internal movement or flow is a powerful if not a necessary agent in producing foliation. It is difficult in fact to see how, without it, unilateral pressures could be set up or maintained under the conditions which obtain in the earth's crust. The components of these schists are such as readily form at high pressures and comparatively low temperatures (not so high at least as those that obtain in contact-zones). This explains their frequently small molecular volumes and their tendency to contain combined water (micas, zoisite). But without dynamo-metamorphism (including displacement, folding and crushing) the rocks we are now considering would not have reached the state of schists.

The coarser-grained rocks contain large crystals or clastic pebbles (Plate IX. Fig. 1), and when flow begins these become distorted, and break down into fine mosaics. Such evidence of movement

* H. C. Sorby, *Quart. Jour. Geol. Soc.*, 1879, vol. xxxv., 'Presidential Address,' p. 88. A. Harker, 'On Slaty Cleavage and Allied Rock-Structures, with special reference to the Mechanical Theories of their Origin,' *Rep. Brit. Ass.*, 1885, p. 846.

† F. Becke, 'Ueber Mineralbestand und Struktur der krystallinischen Schiefer,' *Comptes Rendus Congrès Géol. Internat., Vienna*, 1903, vol. ii. p. 567.

‡ 'Die krystallinen Schiefer,' 1904.

cannot be expected in fine sediments. Even the clastic quartz grains, when quite small, do not readily crush. They seem gradually to melt away as their substance is absorbed by new formed minerals, and tailed quartzes or flaser-bands are not many. But the spots often show elongation and deformation very well, becoming flattened parallel to the foliation, and finally drawn out into wisps of mica. In early stages the movement tends to follow the bedding planes, but when it takes place across them the bands of arenaceous character become discontinuous, being separated into lenticles, while the softer argillaceous or more micaceous substances flow in between them. Where the quartzofelspathic bands are thin they are invaded by growing plates of mica, which spread into them from each side, and if the foliation is transverse to the bedding, these plates have their axes crossing the sedimentary banding, and the relation of the original to the superinduced structures of the rock is very clear.

The large garnets, however, illustrate the internal displacements that have gone on in the rock most clearly. These garnets are the remains of the small garnets of the hornfels, swelled to larger size by constant addition of new matter during the development of the foliation. As the matrix flows past them they form eye-spots with a tail of quartz and felspar at each end. The mica folia bend round them, but flow past their ends, not entering the eddy behind. On the side which faces the movement films of mica often are pressed close against the garnets; on the lee side the mica is conspicuously absent.

In the garnets there are dark enclosures or spots of quartz. Often they are scattered irregularly, in some cases they are in lines indicating a foliation, but often in the schistose hornfelses or stippled schists the enclosures in the garnets are arranged in curved lines. They may even form spiral rings which can be traced, making a complete revolution within a single crystal. The explanation of this peculiarity seems to be as follows: The garnet was rotating under the impulses received from streams of material flowing with unequal velocities past its two sides. It was being rolled along, and was growing larger, like a snowball, during the process. The spiral bands of enclosures mark the successive layers of new material deposited on the surface of the crystals (Plate IX. Figs. 3 and 6).

The crystals of andalusite and chiastolite at first suffer mineral reconstruction without losing their characteristic shapes. Then the soft micaceous aggregates of which they consist are rapidly drawn out into streaks and lenticular patches, which, if the crystals were close together, may coalesce. Finally they pass into micaceous laminæ which blend with the rock matrix, becoming at the same time more coarsely crystalline, and are soon indistinguishable. The kyanite, like the sillimanite, is ultimately transformed into mica.

The identity of the biotite hornfelses with certain of the stippled schists and Moine mica schists can be established by chemical analysis as well as by field and microscopic studies. For this purpose three specimens were selected: the first is the typical banded hornfels, containing small garnets, but no sillimanite or muscovite; the second is a stippled schist, rather fissile though fine-grained, with much muscovite in small plates and many garnets of larger size; the third is a Moine mica schist, well foliated, rich in white mica and coarsely

crystalline. The hornfels retains the bedding and not a little of the pebbly structure of the arenaceous shale. The mica schist is completely metamorphic, and was taken from a point well outside the aureole.

	I.	II.	III.	IV.
SiO_2	63·74	64·98	67·77	66·30
TiO_2	1·11	0·89	1·04	—
Al_2O_3	17·23	11·42	16·42	18·95
Fe_2O_3	0·94	7·21	1·37	4·35
FeO	5·03	5·41	3·68	—
MnO	0·24	0·11	0·33	—
(CoNi)O ..	0·04	trace	0·04	—
CaO	1·60	1·26	1·23	0·60
BaO	nt. fd.	nt. fd.	0·06	—
MgO	1·70	1·71	1·50	1·04
K_2O	3·55	3·95	3·58	3·18
Na_2O	2·97	1·72	2·28	0·54
Li_2O	? trace	trace	? trace	—
H_2O at 105° C. ..	0·15	0·04	0·04	—
H_2O above 105° C.	0·98	1·09	0·74	5·35
P_2O_5	0·24	0·14	0·15	—
F	undet.	—	—	—
FeS_2	0·32	0·13	—	—
Fe_7S_8	—	0·07	—	—
Total ..	99·84	100·13	100·23	100·31

I. Garnetiferous biotite hornfels, 11797, Garbh Allt, a mile south-east of Glencalvie Lodge. (Anal. E. G. Radley.)

II. Fine-grained garnetiferous muscovite biotite schist, 11801, Garbh Allt, a mile south-east of Glencalvie Lodge. (Anal. E. G. Radley.)

III. Garnetiferous muscovite biotite-schist, 12682, on hill ¾ mile south-west of Glencalvie Lodge. (Anal. W. Pollard.)

IV. Shale, Aspatria, Cumberland. (Anal. W. M. Hutchings.) *Geol. Mag.*, 1894, p. 38.

The analyses prove the hornfels and the mica schist to be as much alike as could be expected in two sediments belonging to the same group and of the same type. The stippled schist also differs only in minor respects from the others; it contains least alumina and most iron oxides. All three rocks have too much silica and too little alumina for argillaceous shales; they are poor in lime, though they contain enough to explain the frequency of epidote and sphene in the mica schists. The comparatively large amount of alkalies is by no means unusual in shales, and accounts for the felspar in the hornfelses and the white mica of the schists. These analyses compare well with that of a Carboniferous shale (IV.), containing "a good deal of quartz . . . as evenly dispersed grains," from the coal-field of Aspatria, near Carlisle. The principal difference is that most of the water of the Moine rocks has been dispelled during the metamorphism. J. S. F.

CHAPTER VII.

THE NEWER IGNEOUS ROCKS.

Introduction.

Under the above title will be described all the igneous rocks in the map which appear to have been intruded after the Moine schists had already acquired their foliated characters. They are by no means all free from foliation, but the movements which have affected some of them are believed to have been later than those which first foliated the Moine rocks, and to have had but little effect on these rocks.

The most important member of the group is the unfoliated Fearn granite, in the north-east corner of the map, which must be older than the adjacent Old Red Sandstone, as it has supplied many boulders to the conglomerate at its base. The important group of mica trap dykes must also in part be older than the Middle Old Red Sandstone, as pieces of mica trap have been detected in the coarse conglomerate which forms the bottom of this formation on Meall a' Ghrianain, near the head of Strath Rannoch, as well as in another exposure of conglomerate in a neighbouring burn.*

We shall now proceed to describe, first, the Fearn granite; secondly, various outcrops of peridotite, scyelite and dolerite; then the lamprophyres and mica traps; and, finally, a few acid dykes composed of aplite. This order of description is not intended to imply the relation in age of the rocks described. Some of the mica traps pierce the Fearn granite, but it would be rash, perhaps, to say that all are later than it. Petrographical descriptions by Dr. Flett are given in the latter part of the chapter. C. T. C.

The Fearn Granite.

The Fearn granite occupies an oblong area, six miles in length, and with an average breadth of two miles and a half, that extends in a N.N.W. direction from Torr Leathann to the further side of the Wester Fearn Burn. The siliceous schists along the shore at Kincardine and inland on the Church Hill are filled with a plexus of veins and bosses of the igneous rock, and it is probable that the main mass is continued northwards to the sea at no great distance below the surface. The east and west margins of the mass clearly truncate the main outcrops of three divisions of the Moine Series, while the minor folds and foliation planes are cut by the apophyses and detached veins of the granite, which shows no signs of parallel arrangement of the minerals.

The period of intrusion of the Fearn granite is thus clearly later

* In the adjoining one-inch map 83, however, a mica trap dyke pierces the Old Red Sandstone. The dykes may have had a wide range in time.

than the last movements which produced the foliation of the schists: while the boulders which occur abundantly in the adjoining Old Red Conglomerate prove that it was intruded previous to, and exposed to denudation during the deposition of the Middle Old Red Sandstone.

The rock is a fine or medium-grained reddish biotite granite, with a close resemblance, both in character and in composition, to the Cairngorm granite. It is composed of orthoclase, plagioclase and microcline felspars, abundant clear quartz, sometimes with a tendency to become idiomorphic, and brown mica in small flakes, generally scanty and almost entirely absent in the veins and apophyses. Other constituents are orthite, sphene and magnetite. A typical specimen (11217) of the granite from Cnoc Thorcaill shows microscopically a medium amount of quartz with pink felspar and flakes of biotite. Under the microscope the felspar is seen to be partly potash felspar and partly plagioclase, there being a fair amount of the latter though not so much as of the former. The potash felspar is partly orthoclase and partly microcline, the latter being present in large quantity and frequently containing perthitic intergrowths. The plagioclase is between oligoclase and andesine; it was evidently formed early, as it shows idiomorphic boundaries against the quartz, and is sometimes included in the potash felspar. The chief ferromagnesian constituent is greenish-brown biotite, but there is also a certain quantity of green to yellow pleochroic hornblende in small grains. Sphene and magnetite are present as accessories. The ferromagnesian constituents are somewhat scarce, and the rock approaches in some respects to the quartz syenites. L. W. H., E. M. A.

The schists surrounding the granite are filled, for a distance of a few hundred yards from the margin of the main mass, with veins of granitic material, some of which are coarse in texture, while others are fine-grained or microgranitic.

Veins of more acid muscovite pegmatite occur both within and outside the granite. In the former position they sometimes contain large plates of black mica, in the latter garnets and large crystals of tourmaline. Large blocks, apparently almost *in situ*, that contain tourmaline are seen about 330 yds. N.N.W. of the summit of Torr Leathann.

Good sections of the granite are exposed in the Wester and Easter Fearn Burns and in the head waters of the Strathrory River. At the two latter localities the rock is often soft and disintegrated to a considerable depth, and in places shows spheroidal weathering. At the south end of the area almost vertical jointing is conspicuous, and the direction of the joint planes appears to be parallel to the strike of the surrounding schists. Along the Easter Fearn Burn the granite often shows a laminated structure, the laminæ lying at gentle angles. This structure is distinct from foliation, as the minerals are not arranged parallel to it. The summit of Beinn Clach an Fheadain presents a complex of siliceous schist and granite veins, and both here and on Cnoc Muigh-bhlaraidh, the hill immediately to the south, the igneous rock contains many inclusions of the Moine gneisses.

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Contact-metamorphism of the surrounding rocks has only been observed in the southern part of the area, and appears to be but slight.

The surface planes of the siliceous schist have a glazed appearance owing to the growth of the quartz grains, while the foliation planes of the pelitic gneiss assume a bluish colour, and are more distinct in the neighbourhood of the granite. C. B. C.

PERIDOTITE AND SCYELITE.

Three small exposures, of a rock to be classed with the Newer Igneous rocks, protrude through the peat about 300 yds. to the north-east of the summit of Carn Cas nan Gabhar, and two and a half miles north-east of the head of Loch Morie. From their position they must lie within the hornfels zone, and at a short distance (150 to 300 yds.) from its junction with the augen gneiss. The relations of these exposures to the surrounding rocks are, however, entirely obscured by peat.

The rock differs somewhat in each locality. In one place it is of a greenish colour, probably from weathering, and contains large idiomorphic crystals of hornblende. At another exposure the rock is almost black, coarsely crystalline, and shows schillerisation. It here contains rounded masses of a more acid rock, which appear to be inclusions entirely surrounded by the more basic material. The margins of these masses give the impression of having been melted by the surrounding magma. They are coarsely granitic or pegmatitic in structure, and are often speared by long crystals of a green mineral, probably hornblende. There is no sign of foliation in the rock, and it is doubtful if the granitic inclusions have been derived from veins of the neighbouring augen gneiss. Dr. Flett has described a specimen of the basic portion of this rock (9856) as a biotite hornblende peridotite (scyelite): one from the acid portion (9855) as a quartz diorite. From present observations it would seem that this intrusion is of later date than the augen gneiss, and probably also later than the movements which have produced the foliation of the surrounding rocks. C. B. C.

A somewhat remarkable rock, which may be classed with the scyelite of Carn Cas nan Gabhar, is intruded into the pelitic gneiss on the east side of the Ben Wyvis range. The rock is exposed for a distance of 200 yds. along the burn passing a quarter of a mile N.N.E. of Loch a' Choire Mhoir. A specimen (11126) of what seems to be the normal character of the intrusion, taken from its southern end, is described by Dr. Flett as hornblende mica peridotite (scyelite). The rock (11127) which forms the upper or northern end of the intrusion is more peculiar in composition. We may provisionally give it the name of a quartz mica syenite, but should add that as a syenite it is unique in containing garnet and muscovite. The pelitic gneiss along the margin of this part of the intrusion has been converted into a garnetiferous hornfels, and it has been suggested by Dr. Flett that the abnormal characters of the quartz mica syenite referred to above may be due to the absorption by the igneous rock of a certain quantity of the sediments into which it is intruded. L. W. H.

A peculiar greenish sheet inclining south-west in the burn 1300 yds. outh-east of Dunan Liath is classed as a peridotite (11791). It is faulted and crushed on the north side, but shows no proper foliation. It contains specks of olivine, partly serpentinised, as large as peas,

together with many scattered flakes of chlorite. A description of the microscopic characters is given by Dr. Flett on p. 126, and is accompanied by a chemical analysis by Dr. Pollard.

DOLERITE.

One of the N.N.W. thrusts, going through the hornfels 300 yds. E.S.E. of Cnoc nan Sac, is accompanied by a thin dark green dyke, about two feet thick, which shows no clear foliation, though the hornfelsed sediments on either side are certainly somewhat sheared. Dr. Flett states that this dyke has been an ophitic olivine dolerite in which the augite has now passed into aggregates of small prisms of hornblende (10411). The sedimentary rocks at the sides of the dykes do not seem quite so schistose as might have been expected from their position in a line of sharp contortion, and it is suggested that, like some other schists to be soon mentioned (p.118), they have, after being first rendered schistose, been again slightly hornfelsed by the dyke's action. In another exposure, about 80 yds. further north, a thin band of rock, which seems to represent the dyke just referred to, is much sheared and mylonised, but still shows a few more or less idiomorphic felspars (10412).

A fine-grained dark grey band of dolerite crosses the augen gneiss about three-quarters of a mile slightly west of south of Carn Bhren. It is of a somewhat massive character, and probably part of a dyke. Dr. Flett states that it shows remains of ophitic structure, and describes the microscopic characters on p. 129.

LAMPROPHYRES AND MICA TRAPS.

This group may be described in two divisions, one consisting of bands which are in some places more or less foliated, and the other of bands which are not known to be so. It is not clear, however, that the unfoliated portions of the first division differ from some of the rocks in the second division. The most foliated bands of the first division are thorough schists from side to side, and are difficult to separate lithologically from some of the intrusions placed with the Older Igneous rocks; but most of them are only foliated in part, especially at the sides or in particular localities, while in other localities they are not so. In many cases, also, the foliation is of a very rough type and consists apparently of close parallel fracture-lines without any complete molecular rearrrangement in the interspaces. The comparatively few bands that are completely foliated wherever seen have been separated from those of the older series, either because of strong evidence that they were intruded after the Moine rocks had already acquired a schistose character, or on account of their chemical composition and petrographical characters, which are closely allied to those of some typical lamprophyres, and unlike those of any rock recognised with certainty as one of the Older Igneous series.

With more or less Foliation.

Intrusions of this type are common in the northern half of the map, and appear to be generally in the form of dykes or steep sheets.

The usual strike is slightly south of west, this direction being observed even in many places where the Moine schists are striking nearly north and south.

One of the most accessible and interesting examples is the green unctuous chlorite schist which is found in and near the horizontal thrust in the Garbh Allt, on the north-west side of Alltan Sgeireach (Fig. 10), which has already been referred to in describing the district of Glen Calvie and Cnoc an t-Saic, (Chapter V.). The main band of green schist in this locality varies in thickness from one foot to four feet, and the minor subparallel streaks are never more than a few inches. The main band contains various thin calcareous strings and many crystals of pyrites, the latter without any appreciable deformation. It breaks up readily into small phacoids, bounded by lines of strain-slip, thus making an "oyster-shell rock." The phacoids and foliation planes are thrown into a succession of close folds, with axial planes generally inclining north-west, but these folds do not affect the sides of the band nor the adjacent Moine rocks. There can be little doubt that these green schists represent intrusions which were first injected along the thrust and parallel lines of weakness, and subsequently sheared by renewed movements along the thrust. No parts remain unsheared. From the result of the chemical analysis, given on p. 125, Dr. Flett infers that the original rock was of lamprophyric type, and probably a minette which contained olivine or more green pyroxene than is usual in rocks of this class.

It should be stated that, in spite of the complete foliation of this chlorite schist, it is not probable that the shearing in the adjacent hornfels was all brought on at the same time as that in the green schist. No doubt part and possibly most of the shearing in the hornfels was contemporaneous with the first formation of the thrust, and this was probably prior to the irruption of the lamprophyre. It cannot, therefore, be maintained that the sediments near the green schist have acquired their present schistose characters in consequence of movements subsequent to the intrusion of the Newer Igneous rocks, even if the lamprophyre could be definitely proved to belong to that series.

One of the almost vertical N.N.W. thrusts in Garbh Allt, about 940 yards S.S.E. of the foot of Alltan Sgeireach, is also accompanied, on the north side of the burn, by a contorted chlorite schist of much the same character as that referred to in the last paragraph. The caution given in the last paragraph respecting the age of the shearing in the adjacent sediments may be repeated here, and has to be applied also to the shearing in the augen gneiss.

In other parts of the Garbh Allt, 575 yds. and again 850 yds. S.S.E. of Alltan Sgeireach, intrusive sheets cross the intermixed sediments and granitic gneiss, and the marginal portions of these sheets are converted into chlorite schist, with a foliation parallel to the side, though the interiors remain quite massive. The interior of the thickest sheet weathers with small projecting spots, about a third of an inch in diameter, and contains many irregular reddish strings which appear to be more felspathic than the rest. A specimen (10410) of this interior is called biotite vogesite by Dr. Flett. The interior of one of the sheets in the locality higher up the burn is a fine-grained

dark grey rock, and also weathers with a somewhat spotted surface: the specimen sliced (10409) consists of greenish biotite and felspar, principally orthoclase, with a little quartz. The rock is regarded as a minette, and its igneous structures are in fairly good preservation.

The most distinct of the sheets in the higher locality is about 12 ft. thick, and inclines somewhat north of west at about 20°, while the bands of granitic gneiss and altered sediment which it cuts are inclined steeply south-east. Though the foliation in the marginal portions of the sheets is well developed, no parallel foliation or clear modification of the common foliation is discernible in the granitic gneiss. The sheet in the lower locality inclines north-west, at about 24°, and also cuts the granitic gneiss and the sediments quite distinctly. These sediments are in the form of pelitic or semipelitic schists,* and it is noteworthy that they have been rendered somewhat hard and splintery close to their plane of contact with the sheet. They were evidently schists before the sheet was intruded, and by its action they appear to have undergone a certain amount of hornfelsing, which has partly obliterated the indications of the earlier schistosity. The later shearing which foliated the marginal portions of the sheet cannot have again sheared the sediments in any appreciable degree.

C. T. C.

An intrusive sheet with an even upper surface, inclining north-west, is traceable 60 or 70 yds. in the burn a mile W.S.W. of the foot of Crom Loch. It cuts the bedding and foliation of the Moine rocks very distinctly, these being inclined south-east at high angles, but is itself foliated throughout with a foliation parallel to its surface. Nothing to correspond to this foliation is observed in the Moine rocks, and it seems clear that they must have been essentially the same as they are now, both as regards position and character, at the time the sheet was intruded into them. The movements subsequent to the intrusion have sufficed to convert the sheet into a schist, but they have had no appreciable effect on the Moine rocks. C. B. C.

A dark grey sheet about 10 ft. thick, weathering in small knobs, is well seen in the crags about 530 yds. E.N.E. of Mullach Creag Riaraidh. The matrix appears very compact macroscopically, but in the thin slice (10879) it is seen to consist of well foliated hornblende biotite schist. In this matrix are embedded many small oval quartz blebs, felspar phenocrysts, sometimes half an inch long, bits of hornblende an inch long, and pieces of some composite rock—perhaps a Moine schist.

The section in the crags a mile and a quarter slightly east of north of Deanich Lodge shows, as already mentioned in describing group iv. of the Older Igneous Intrusions, a sheet of lamprophyre, intruded along a thrust. The thrust has displaced a calcareous biotite schist, representing an intrusion, which was foliated before the thrust took place, and, consequently, also before the intrusion of the lamprophyre. The lamprophyre contains many flakes of biotite and a good deal of reddish felspar, but occurs only in torn patches along the thrust, and breaks up into phacoids with the flatter sides parallel to the thrust plane. Further south-west, along the direction of this crushed sheet, exposures of even more crushed rock are seen in the burn nearly a mile north-west of Deanich Lodge, and

* Of the type called stippled schists in Chapter V.

in one place the rock is represented by a very thin green schist. The foliation in this schist is parallel to its sides, and seems to be unaccompanied by any corresponding structure in the adjacent Moine rocks.

A crushed reddish rock somewhat similar to that described in the crags mentioned in the preceding paragraph is seen in places on the north-west side of the valley near Deanich Lodge, in torn patches along a nearly horizontal ledge (Plate II.). The ledge can be traced more than half a mile, and represents an important line of movement, inclining northwards, on either side of which the Moine schists are somewhat differently inclined. A comparatively uncrushed specimen (10379) of the sheet occurring along the movement line is stated by Dr. Flett to be a foliated minette.

About a mile further E.N.E., in the apparent direction of the intrusive patches just referred to, a sheet of lamprophyre makes a blocky crag on the south side of Gleann Mor, and is in one place about 15 ft. thick. It contains many flakes of biotite, sometimes half an inch long, and various irregular badly defined patches and strings, which appear to be more acid than the rest of the rock. In places this sheet is represented by many thin veins which penetrate and isolate angular pieces of brecciated siliceous Moine schist, which are in considerable excess of the lamprophyric rock, and look like portions of some old crush breccia formed out of schist. The ordinary unfoliated type of the lamprophyre is occasionally seen close to the brecciated siliceous schist, but shows no indications of brecciation in itself. In parts, however, the lamprophyre is rudely foliated, but never so perfectly as an adjacent calcareous biotite schist, which occurs a little higher up the hillside, and is referred to the group iv. of the Older Intrusions.

A rudely sheared green igneous rock which has been traced a third of a mile, in a direction slightly south of west, in a burn on the west side of Glen Calvie, inclines north, while the Moine schists in which it occurs dip steeply south. It contains many veins of carbonate and quartz, some of which contain small specks of pyrites and galena.

In the augen gneiss of the Inchbae plutonic mass, a crushed intrusive rock runs along the burn rather more than a mile slightly north of west of Carn Mor. It can be traced more than 200 yds., and in some places, where it is but little crushed, it shows the characters of a mica trap distinctly, though in others it is so much sheared that it can no longer be recognised as an igneous rock.

Without Foliation.

As already stated, it is doubtful whether there was any difference in original character between the unfoliated rocks and many of those which are foliated. The general direction of the dykes of both divisions is slightly south of west, but in the unfoliated dykes there are some notable exceptions. Among these, special mention may be made of the group of mica traps which strike W.N.W. near Creag na Ceapaich and cross the burn further south-east (10961, minette). A still more marked divergence is shown by a fine-grained dark dyke, apparently a diorite, which has been traced on the south-east side of Dunan Liath, for half a mile in a direction slightly west of north.

Several unsheared dykes are seen within the Carn Chuinneag

plutonic mass. One of these which occurs next an unfoliated diorite belonging to group i. of the Older Intrusions, rather more than half a mile north-west of Carn Dubh, Glen Calvie, is rather coarse-grained, weathers with a knobby surface, and contains many veins which are redder and more felspathic than the rest of the rock. It shows much biotite and some pale green augite, and is classed as augite minette (10864, 10921) by Dr. Flett. C. T. C.

An east and west dyke half a mile west of Creag na Ceapaich contains many thin needles of hornblende as well as flakes of biotite (10963), and is consequently allied both to the vogesites and the minettes. C. B. C.

In Northern Kincardine some of the mica traps are intrusive only into the schists, while others only pierce the granite, but they are all probably of later date than the latter. The largest of these, a pinkish dyke about 15 ft. in width, pierces the quartz schists in Allt Eiteachan about three-quarters of a mile above Gradal. It runs in a direction somewhat south of east. Nearly half a mile further south, and a little way up a branch stream, a very soft-weathering brown dyke with abundance of yellow mica cuts the schists. It has the same direction as the last.

In the Wester Fearn Burn, three-quarters of a mile below Lubnaceardaich, and close to the upper fall, a brownish mica trap dyke 3 ft. in width, with an east and west course, pierces the granite. Below the lower fall there are two dykes which seem to be of a more basic character. One of these, which is 4 ft. broad and hades steeply to the west, may be examined at the mass of rock that here projects into the river. It contains a good deal of mica. The other forms a deep nick in the rocks south of the fall. Both run in a north-easterly direction. Some 600 yds. west of Wester Fearn house a dark basic dyke, rich in biotite and from 1 to 2 ft. in width; crosses the foliation of the schist in a northerly direction. W. G.

Several dykes of unfoliated igneous rock that may be referred to the later intrusions traverse the schists in the valley of Loch Glass. Two of these occur in the burns which join the Abhuinn Beinn nan Eun on the north side, above Wyvis Lodge. They are described by Dr. Flett respectively as minette (11025), and augite minette (11024).

An east and west dyke of hornblende lamprophyre is well exposed in the burn half a mile north of Lochluichart Lodge, and is seen at intervals for two miles further west.

APLITE DYKES.

Two thin dykes of aplite are seen on the north-east side of the valley a little below the foot of Loch Glass. One is exposed at the side of a band of pelitic schist about half a mile east of Kinloch. The other (9853) is exposed nearly a mile south-east of Kinloch, and strikes in a nearly east and west direction. C. B. C.

Petrography.

For convenience of petrographical description the lamprophyric dyke-rocks of this sheet may be divided into three groups, viz. :— the normal lamprophyres, the sheared lamprophyres, and the lampro-

schists, the last named group including those types which are perfectly schistose and have lost their igneous structures completely.

Lamprophyres of Normal Type.

In the north-east corner of the Sheet, around the Newer Granite mass of Fearn and Beinn nan Oighrean, there are several dykes of very typical augite minette. They are brownish rocks with shining plates of biotite, and resemble closely some of the well known lamprophyres of the Lake District of Cumberland. Their most conspicuous mineral is biotite, which in the microscopic sections has reddish brown to pale yellow colours, often with narrow dark borders and sometimes also deep brown centres. It is uniaxial, very fresh, and in its outlines always shows hexagonal form, though the larger crystals have zigzag boundaries resembling the plan of a fortification. It often contains enclosures of apatite, rarely of augite. The pyroxene is pale green, nearly colourless, and its crystals are eumorphic. They are seldom twinned, and are mostly somewhat decomposed into chlorite and calcite. Glomeroporphyritic groups of biotite and augite occur, in which the two minerals are sometimes intergrown.

The felspar is nearly all orthoclase, though polysynthetic crystals are present also; it is often too turbid for accurate identification; but is mostly alkali felspar with low indices of refraction. Quartz occurs interstitially in small amount in all the slides. Apatite is very abundant, usually in well shaped hexagonal prisms. Magnetite is the only other ingredient, but in some slides pseudomorphs of carbonates and magnetite are found which probably represent original olivine.

The structure varies, being panidiomorphic as a rule, with all the minerals except the quartz showing good development of crystalline form. In other cases the felspars are grouped in brushes or divergent bundles of narrow rods, a structure very characteristic of the rocks of this group. Xenocrysts of quartz with halos of amphibole, in needles directed towards their centres, are occasionally present. In one of the slides the micas have subparallel orientation and are often bent and crumpled, the result of the rock being injected into narrow sinuous fissures when partly crystallised. The later minerals, quartz and felspar, however, are never crushed, and there is no granulitisation.

Minettes of this type have been met with in the Allt Eiteachan three-quarters of a mile south-west of Gradal (10160), and half a mile E.S.E. of Creag na Ceapaich (10961).

Sheared Lamprophyres.

The lamprophyres of the second group consist of the same minerals, biotite (hornblende), augite, alkali felspars and quartz, in much the same proportions as the rocks above described (Plate X. Fig. 1). The slides cut from the two series differ, however, in so many characters that they are easily distinguished. The biotite of the sheared lamprophyres is always green, with pleochroism from pale yellow and pale green to dark green or brownish green. It very rarely shows idiomorphism; occasionally a rectangular vertical section can be seen, but most of them are lenticular, tailing off at both ends, and very often the micas are frayed and wisp-like. Basal sections are never hexagonal but

quite irregular in outline; they often contain perfect webs of sagenite. Except apatite and iron oxides there are few inclusions, but sometimes idiomorphic yellow epidotes occur in the mica. Augite is distinctly rare in these rocks; it is always pale green, similar in colour, habit and optical character to that of ordinary minettes. The hornblende occurs in short or long prisms, six-sided in cross sections {110} {010} but rarely terminated by crystal faces; it is occasionally simply twinned on the orthopinakoid. In the coarser-grained rocks the prisms are short and broad, in the finer-grained they are long and acicular. Exceedingly minute needles of green amphibole sometimes lie in the quartz and felspar. The colour is nearly always green, rarely brownish green. The felspars are alkali felspars, with indices of refraction below those of balsam and quartz. They are orthoclase or anorthoclase with irregular speckled polarisation tints, microcline (seldom) and albite. The albite has albite twinning, but rarely pericline or Carlsbad twinning, and the felspars have often turbid centres and clear borders. Quartz occurs in all the rocks as an interstitial mineral. Micropegmatite, sometimes rather coarse-grained, is not unfrequently present, but never in great quantity.

The principal accessory minerals are apatite (euhedral or in irregular grains) and yellow epidote. Orthite also is strikingly common; it is often not eumorphic and is usually enveloped in epidote. The apatite crystals are not only numerous but often of exceptionally large size. Iron oxides are singularly scanty: many of the slides contain none: in others they occur, but only in very small amount. Pyrites, on the other hand, is common, being present in all the rocks and often euhedral. Sphene in small brownish or nearly colourless grains is frequent also: of secondary products the commonest are chlorite and areas of granular calcite.

The structure of these rocks varies according to the amount of crushing and recrystallisation they have undergone. None of them is really free from cataclastic developments, but in some the igneous characters are fairly well preserved (Plate X. Fig. 1), and in most there are portions where original structures can be recognised, though in the greater part of the rock these are much disguised. The crushing, in fact, has often been local, and phacoids remain in which its effects are at a minimum. The femic minerals have had eumorphic forms in the first condition of the rocks. This is still visible in the hornblende and the augite, both of which occur in prisms with idiomorphic transverse sections, the augite being octagonal while the amphibole has prism faces and clinopinakoids. In the finer-grained rocks the hornblende prisms are long and narrow: the augite (which is distinctly rare) is two or three times as long as broad. The biotite has more frequently lost its crystalline outlines than the other femic minerals. Of the salic constituents the felspars in the least crushed areas are subhedral; where there is a fair amount of interstitial quartz the angular shapes of the original crystals are often discernible. The quartz alone was wholly anhedral. From what has been said it is clear that the original lamprophyres were of the panidiomorphic type.

The effects of crushing, as usual, are twofold: (a) the development of new minerals, and (b) the modification of original structure. Of the new minerals the principal are biotite, epidote and sphene. The

biotite is always green, and has very often formed from hornblende, as can be established by the occurrence of pseudomorphs in every stage of development. In many cases the mica is in parallel growth with the amphibole, its basal planes resting on the prism faces of the original mineral. By complete replacement the mica forms two systems, with basal cleavages meeting at the angle of the prism cleavage of amphibole (Plate X. Fig. 1). Perfect pseudomorphs of this character are not infrequent, and have often the outlines of transverse sections of hornblende. Longitudinal sections of these amphiboles show the cleavage of the mica parallel to that of the hornblende; irregular patches of the new mineral lie in a background of the original one. The twinning of the hornblende, being on the orthopinakoid, has no effect on the structure of these pseudomorphs. In other cases a cluster of green mica shows a core of hornblende, highly irregular in form, with the edges of the biotite plates pushing into it from all sides. Lastly, there are tangled clusters of green biotite in which no remains of amphibole can be found. These groups form lenticles, augen or irregular streaks, having evidently suffered from pressure and movement. The biotite clusters are one of the most characteristic features of these rocks, and distinguish them at a glance from all other lamprophyres. They are "relict" structures, the remains of original femic phenocrysts. Many of the rocks have a spotted or streaky appearance in the hand specimen from this cause.

The pale green pyroxene apparently does not suffer transformation into biotite but into green actinolitic hornblende, and is equally frequently decomposed by atmospheric action into calcite and chlorite. The amphibole forms on the periphery of the pyroxene, gradually spreading inwards, and complete pseudomorphs occur. It is not certain that this hornblende at a later stage passes into biotite, but it is probable, as in some of the most sheared rocks only biotite occurs with the salic minerals. The non-occurrence of biotite after augite is all the more remarkable, because this change is one of the best marked features of the Carn Dearg lamprophyres of Northern Perthshire,* a group with which these sheared lamprophyres have many affinities.

With secondary biotite, epidote also is formed. It is always yellow, and very commonly in short, stout, eumorphic prisms. The epidote is often found in the centre of groups of biotite, but sharply crystallised minute prisms are sometimes embedded in single plates of the mica, both being then of metamorphic origin. Brown orthite, often zoned, is excessively frequent. Probably there are no other British rocks in which this mineral is so important. Although usually surrounded by epidote, there is nothing to show that it is secondary; and when its prisms are long and narrow they are often broken across, and the fragments shifted by movements of the matrix. The sphene may be in part primary, but its irregular outlines indicate that it may have formed at the expense of titaniferous iron oxides during the metamorphic process, and the absence of opaque cores of magnetite and ilmenite shows that the transformation has been complete. Chlorite is rare, and probably always a decomposition product. Rutile appears only as sagenite in the micas. The abundance of carbonates is a characteristic of all lamprophyres.

* 'The Geology of the Country around Blair Atholl, Pitlochry and Aberfeldy,' *Mem. Geol. Survey*, 1905, p. 125.

The quartz, felspar and micropegmatite become granulitised under pressure, and pass into a mosaic in which calcite, sphene and epidote are intimately mingled. Small flakes of mica appear also in this aggregate. Often remains of igneous structures are found in this groundmass where the shearing has not been excessive. The felspar prisms may have nearly square or rectangular outlines. Very frequently they are traversed by cracks, and break up under crossed nicols into patches which indicate the effects of pressure. Small areas of micropegmatite often also retain their identity when the rest of the quartz and felspar are granulitised. The quartz occasionally occurs as rather broad areas with irregular boundaries, and these may be segregations of silica excreted from the other constituents, showing mineral reconstruction under pressure. The carbonates which often form an important part of the groundmass are always granular and anhedral. Where the rocks are much crushed they form flaser or lenticular streaks. The apatites, which are usually in short, stout hexagonal prisms, very abundant and sometimes as large as the felspars (half a millimetre long), maintain their idiomorphism in the most surprising fashion, even in rocks which show evidence of considerable movement.

A few of the localities where lamprophyres of this group occur may be mentioned here, though it should be understood that as the metamorphism is very variable the particulars given refer only to the sliced specimens. Of two dykes from the east shore of Loch Glass opposite Culzie Lodge one (9861) is a vogesite, nearly normal, with brownish idiomorphic hornblende; the other (9862) is a minette with much epidote and pale brown biotite, and preserves a good deal of its igneous characters, though sheared. The replacement of hornblende by green biotite is well seen in a lamprophyre from the burn 440 yds. N.N.W. of the outlet of Loch Bad a' Bhathaich (12375), in another from half a mile north-west of Carn Dubh (10864, 10921), and in one from the burn flowing south from Creachan nan Sgadan (11024). All of these contain augite, as also does an excellent specimen from the Wester Fearn Burn, a mile and a half south-west of Wester Fearn.

Foliated minettes with much biotite (green or brownish) and often containing orthite, come from the three following localties: the waterfall in the burn east of Creag a' Ghaoirr above Loch Glass (11025); one-third of a mile slightly east of north of Deanich Lodge (10379); and 1000 yds. N.N.W. of the outlet of Lochan Sgeireich (10389).

Lamproschists.

From the sheared lamprophyres we pass to the lamproschists, rocks which have lost all igneous structures and are completely metamorphic. These are soft fine dark green lustrous schists, with a very perfect sinuous foliation which gives rise to wavy or crumpled surfaces in the hand specimens. A very fine example of these rocks is found in the thrust plane on the Garbh Allt (Fig. 10) about a mile south-east of Glencalvie Lodge (Plate X. Fig. 2). This thrust plane is a line of secondary movement in the banded hornfelses of the metamorphic aureole, and the lamprophyre sheet has been converted, by these movements, into a fine dark green schist with the foliation sharply twisted into a succession of small folds, the

limbs of which are often considerably inclined to the boundaries of the sheet.

Its components are pale green hornblende, yellow and greenish yellow biotite, felspar, quartz and carbonates. Biotite on the whole preponderates; its scales lie in the foliation planes and are perfectly fresh; their pleochroism is from pale yellow to dark brown. Enclosures are few or none, and the form of the plates is quite irregular. The amphibole needles are sometimes bounded by simple prism faces. At other times they show also small orthopinakoid planes. They are very pale green and feebly pleochroic, (X) colourless, (Y) pale green, (Z) slightly darker green. Quartz, orthoclase, albite and carbonates, all in rounded or irregular grains, are the other constituents. Epidote, orthite and sphene are rare or absent, but pyrites occurs in all the sections.

The biotite and hornblende form moderately well defined folia separating lenticular paler-coloured aggregates of quartz, felspar and carbonates, containing an admixture of the other minerals. Quartzofelspathic augen occur also, and apparently represent harder portions of the original rock which were difficult to crush, or ocelli, such as occur in many Scotch lamprophyres. The rock is a perfect schist, in which all traces of original igneous structures have been effaced.

	I.	II.
SiO_2	50·76	50·98
TiO_2	0·76	1·25
Al_2O_3	12·20	16·13
Fe_2O_3	1·19	4·20
FeO	6·65	3·24
MnO	0·30	0·17
(CoNi)O	0·06	trace
CaO	6·26	5·50
MgO	11·75	7·28
BaO	0·04	0·20
Li_2O	trace	trace
K_2O	4·79	4·82
Na_2O	2·16	2·99
H_2O at 105° C.	0·22	0·44
H_2O above 105° C.	0·66	1·46
P_2O_5	0·28	0·74
CO_2	1·39	0·58
FeS_2	0·18	0·43
V_2O_3	0·03	trace
Cr_2O_3	0·10	trace
Cl	nt. fd.	0·07
Total	99·78	100·48

I. Biotite hornblende schist (lamproschist), 11800, sheet intruded along thrust plane, Garbh Allt (Fig. 10), a mile south-east of Glencalvie Lodge. (Anal. E. G. Radley.)

II. Minette, E 3660, Gannel Quarry, Pentire, Newquay, Cornwall. (Anal. W. Pollard.) 'The Geology of the Country near Newquay,' *Mem. Geol. Survey*, 1906, p. 61 (also SrO, tr.; less O = 0·02, total = 100·46).

The analysis (I.) of the most perfectly metamorphic lamproschist of this region may be compared with that of a post-Carboniferous lamprophyre from Cornwall (II.). The two analyses show the closest resemblance, and there is no room for doubt as to the original nature of the biotite hornblende schist. The only difference which calls for remark

is the less amount of alumina and higher percentage of magnesia in the schist, which would indicate that olivine had been present in the latter, or that it had been more rich in the green pyroxene that is so frequent in rocks of this class.

Peridotite and Scyelite.

A curious dark green very fine-grained mica hornblende schist occurs (as a dyke ?) in the Kincardine Burn, half a mile north-east of Gradal. Under the microscope it is resolved into an aggregate of pale green actinolite and yellow or greenish yellow biotite, similar to those of the lamproschists. The hornblende forms clusters with a tufted, subradiate arrangement. The mica occurs also in aggregates of little anhedral plates. The foliation, consequently, though clear, is of a nodular rather than linear or lamellar character. Iron oxides, sphene, quartz, alkali felspars, carbonates and apatite are present also, though in small quantities, and complete the mineralogical resemblance. The great abundance of femic minerals, however, shows that this was probably a peridotite, of the same magmatic succession as the lamprophyres. We are reminded of the association of peridotites with the Carn Dearg lamprophyres of Perthshire, though in these rocks there has been a considerable development of talc, which is absent in the dyke in the Kincardine Burn. The syngenetic association of peridotites and lamprophyres has so rarely been recorded that this is an occurrence of the highest interest from a petrological standpoint.

In Diebidale Forest there is an interesting altered peridotite in the burn two-thirds of a mile south-east of Dunan Liath. The rock is very dark and nearly massive. It contains grains of olivine, a quarter of an inch in diameter, visible in the hand specimen. The matrix is compact, very fine-grained, non-schistose, with a velvety lustre.

In the microscopic slides the olivine forms rounded grains, outlined by thick deposits of magnetite, which also fill the cracks in the mineral. Within the olivine, magnetite occurs in excessively small granules, giving it a greyish colour. Colourless serpentine accompanies the magnetite, and carbonates and iron oxides may ultimately replace the olivine. The matrix of the rock consists of tremolite, pyroxene and chlorite, intimately mixed. They are all in very small grains, never eumorphic, but granular or fibrous, and very difficult to distinguish from one another. The hornblende is almost colourless, and may be assigned to tremolite ; cross sections are identified by the amphibole cleavage. The double refraction is unusually low for this mineral. The chlorite is colourless and always lamellar. The augite also is white. It shows no traces of crystalline form, but its grains have the cleavage angles of pyroxene and are optically positive. These grains may be the unaltered remains of the original pyroxene of the rock. Dusty iron oxides, patches of carbonates, and probably also scaly talc occur in the matrix.

The undestroyed kernels of olivine give the rock a " relict " structure. Most of the tremolite must have been formed after olivine ; in fact, subradiate halos of colourless amphibole can be seen spreading outwards from the olivine grains (a kind of pilite formation). In the matrix there are many large tabular crystals of clinochlore ; these

are colourless, with a double refraction similar to that of felspar and very pronounced polysynthetic twinning. They are very well formed, the basal planes being smooth and perfect, but the lateral faces are somewhat uneven or dentate. Some of these crystals are one-twelfth of an inch in diameter. They are evidently of metamorphic origin (poikiloblastic); a very noteworthy feature is their haphazard orientation; and this accentuates the non-foliated character of the groundmass in which they lie.

The rock is traversed by a system of well marked parallel cracks which are filled with colourless serpentine. These cracks are an indication of tension, and often seen in fine serpentines, *e.g.*, the Lizard rocks. They traverse the olivine as well as the matrix, but are most obvious when the mineral is decomposed. In the fresh olivine they often die out towards the centre, but appear again near the opposite edge.

	I.	II.	III.	IV.
SiO_2	41·01	39·58	42·10	38·6
TiO_2	0·66	0·10	—	—
Al_2O_3	5·00	3·19	3·28	3·7
Fe_2O_3	5·52	4·70	8·27	7·6
Cr_2O_3	0·14	0·20	—	0·1
V_2O_3	0·03	nt. fd.	—	—
FeO	8·66	2·76	2·13	7·8
MnO	0·47	0·34	0·70	—
CoO	0·05	0·16	—	—
NiO	0·17			
CaO	4·43	1·09	3·77	7·7
MgO	26·92	36·21	30·65	27·7
K_2O	0·25	0·06	1·90	0·2
Na_2O	0·98	0·28		
Li_2O	nt. fd.	trace	—	—
H_2O at 105° C. ..	0·43	0·51		
H_2O above 105° C.	4·95	10·79	7·73	6·4
CO_2	0·76	0·24		
P_2O_5	0·10	0·16	—	—
S	nt. fd.	nt. fd.	—	—
CuO	trace	—	—	—
BaO	? trace	nt. fd.	—	—
Total ..	100·53	100·37	100·53	99·8

I. Peridotite, 11791, burn 1300 yds. south-east of Dunan Liath. (Anal. W. Pollard.)

II. Bastite serpentine, E 5031, Poltesco, Ruan Minor, Lizard, Cornwall. (Anal. E. G. Radley.)

III. Scyelite, Achavarasdale, Caithness. J. W. Judd in *Quart. Jour. Geol. Soc.*, 1885, vol. xli. p. 402.

IV. Olivine-diallage peridotite, north-east of Loch Garabal, Argyllshire. (Anal. J. H. Player.) *Quart. Jour. Geol. Soc.*, 1892, vol. xlviii. p. 115.

The analyses cited above throw much light on the source of the chlorite-tremolite-augite aggregate, which forms the matrix of this peridotite. Clearly it was not enstatite (cf. analysis II.), as in that case the rock should have contained more magnesia and less lime. In all probability it was diallage, though some hornblende may also have been present. The diallage-olivine rock, or wehrlite of Garabal Hill, one of the basic facies of the Newer Granites of the Highlands (IV.), is sufficiently near the Dunan Liath rock in composition to render this conclusion highly probable. One of the remarkable features

of the peridotite from Ross-shire is the excellent preservation of the olivine, while the diallage is almost completely altered, for this is a reversal of the usual sequence in rocks of this type.

The scyelite of Carn Cas nan Gabhar is the third rock of this class which has been discovered in the North of Scotland. The type rock is that which was found by Sir Robert Sinclair at Loch Scye, Achavarasdale, Caithness, and fully described by Professor Judd,* with an analysis by Dr. H. R. Mill. Another scyelite was obtained some years ago at Cape Wrath, though no account of it has yet been published (3052). The macroscopic characters of these peridotites are very distinctive; they are all coarse-grained, with prisms of hornblende sometimes one inch in diameter, which have their cleavage surfaces coated with thin films of bronze-coloured biotite, and speckled with small rounded grains of dull green serpentine after olivine (lustre-mottling).

Their principal components are hornblende, biotite and olivine (Plate XI. fig. 6). The amphibole shows perfect cleavage, but has ill defined crystalline faces. It is green in thin sections, and the tint varies from yellowish green to nearly colourless. The pleochroism is seldom strong, especially in the paler crystals, and the extinction angle about 15°. The biotite is straw yellow, or brownish yellow, with moderately strong pleochroism, but some sections are nearly white. Fresh olivine is present in small quantity, and there are also many characteristic pseudomorphs of serpentine and magnetite after that mineral. The structure, as is usual in peridotites, is poikilitic, the olivine being enveloped in large plates of hornblende and to a less extent in biotite. Professor Judd has suggested that the hornblende has developed after augite or diallage, but there is nothing to render this probable in the sections of the Carn Cas nan Gabhar scyelite. Dark platy inclusions sometimes occur in the hornblende, and also in the olivine, but schillerisation of this type does not necessarily imply a secondary origin for the amphibole. The biotite, which is often in fairly large, irregular crystals, very frequently occurs in parallel growth with the hornblende, so that the dominant cleavages of the two minerals have the same orientation.

The accessory constituents are magnetite, apatite and a little chromite. Of the secondary minerals the principal are serpentine (after olivine), chlorite (after biotite), sphene (with the iron oxides), tremolite and talc. The two last are colourless, occurring as fibres and scales filling irregular spaces. The white tremolite has often grown upon the surface of the primary green hornblende, so that the two have nearly the same extinction, and there can be little doubt that both of these minerals are secondary products after olivine or some other ferromagnesian silicate. Deposits of carbonates have been laid down in the cleavage cracks of the biotite, and the mica is often somewhat crumpled by the expansion which takes place when the olivine changes to serpentine.

With the scyelite a massive dark green rock occurs which might be described as a quartz diorite. It is not so coarsely crystalline as the scyelite, though thoroughly granitic in texture, and it is so rich

* J. W. Judd, 'On the Tertiary and Older Peridotites of Scotland,' *Quart. Jour. Geol. Soc.*, 1885, vol. xli. p. 401.

† See also J. J. H. Teall, 'British Petrography,' 1888, Pl. V. fig. 2.

in hornblende as to approach closely to a hornblendite. The amphibole is dark green in section, and there is also a considerable amount of brown biotite (of deeper colour than the biotite in the scyelite), which may be in parallel growth with the hornblende. Pale patches in the centre of hornblende crystals suggest that at one time the rock contained some augite, and there are a few radiate clusters of tremolite needles which may be after olivine. The most striking feature of the rock, however, is the presence of quartz and alkali felspar as an interstitial material forming less than one-third of the whole mass. Very frequently these are intergrown to form coarse-grained micropegmatite. There is no basic soda-lime felspar. The rock is far from being a normal diorite; neither is it a syenite. The abundance of ferromagnesian minerals in a mesostasis rich in silica and alkalies is a feature which recalls the lamprophyres, but the hornblende is dark green and does not belong to the brown variety which characterises the vogesites.

To the list of Scottish scyelites we must also add one obtained by Mr. Hinxman in a burn N.N.E. of Loch a' Choire Mhoir, Ben Wyvis. In hand specimens the rock has the typical appearance of the scyelites, showing large dark green crystals of hornblende, with cleavage planes coated with silvery mica, and spotted with rounded inclusions of olivine. Under the microscope (11126) the rock proves to be by no means fresh. For the most part the olivine is converted into talc, carbonates and tremolite, and the hornblende and mica have been replaced by chlorite. There are portions of the slides, however, in which large amphibole crystals can be seen enveloping rounded grains of serpentine after olivine, in the manner which is characteristic of peridotites.

Dolerite.

In several parts of this Sheet basic dykes (dolerites) occur which show modifications due to pressure, but have not completely lost their original igneous structures (see p. 116).

Three-quarters of a mile slightly west of south of Carn Bhren there is a small basic dyke in the granite represented on the one-inch map. This is almost a massive rock, consisting of green hornblende and plagioclase felspar (Plate X. Fig. 5). It shows remains of ophitic structure, as the felspars are partly idiomorphic, with broadish rectangular sections, while the hornblende forms irregular masses which wrap around them. No augite or olivine are left in the rock; the hornblende is dark green, and though sometimes forming fairly large plates, more frequently consists of aggregates of small anhedral crystals. The rock contains some calcite, a little epidote, iron ores and sphene. The felspars are labradorite (with margins of andesine), and are turbid with very minute dark inclusions: a little oligoclase and albite also occur in the slides. This is a good example of the basic dykes not yet transformed into schists.

Another example occurs 300 yds. slightly south of east of Cnoc nan Sac (10411). This rock is porphyritic, and its groundmass still shows ophitic characters. The phenocrysts have been olivine, augite and hornblende; the olivine is transformed into biotite, hornblende, magnetite and carbonates, the augite into masses of greenish hornblende which still preserve the octagonal outlines of pyroxene. The

groundmass shows lath-shaped felspars surrounded by granules of hornblende, indicating the ophitic structure of the original rock. A rounded steam cavity is visible in the section, and is occupied by calcite, quartz and pyrites. In this case, as in some of the gabbros, there has been considerable alteration of the minerals of the original rock, but the igneous structures are well preserved. J. S. F.

CHAPTER VIII.

OLD RED SANDSTONE.

Introduction.

The Old Red Sandstone within the limits of the one-inch map under description is chiefly found in the south-eastern portion, where it occupies an area of about 30 square miles. This may be called the Alness and Evanton area.

Separated from this large area by wide intervals of schist, never less than 9 miles in width, are various outliers further west (Plate XII.), the largest of which, in Strath Rannoch and the eastern side of Strath Vaich, amounts perhaps to 6 or 7 square miles. This may be called the Strath Rannoch outlier. Smaller ones occur on Meall a' Ghrianain (between Strath Rannoch and Strath Vaich), Beinn nan Cabag and Beinn a' Bhric, both a little north of Loch Luichart, and in other places, as will be subsequently described.

The evidence afforded by the western margin of the Alness and Evanton area, and also by the outliers further west, shows that the Old Red Sandstone strata were deposited on a very uneven surface of the older metamorphic rocks. The basal beds in different localities may, therefore, occur on different geological horizons. Nevertheless it seems quite possible that the western outliers, none of which have yielded distinctive palæontological evidence, may belong to the same division as that to which all the strata in the Alness and Evanton area have been referred, on the evidence of the fossil fish remains found a little within the adjoining Sheet 94 (see Appendix I.). This is the Middle or Orcadian Division.

Attention should be called to the fact that while certain upper conglomerates, to be shortly described in the Alness and Evanton area, contain abundant pebbles of Cambrian and Torridonian rocks derived from areas to the west, beyond the Moine thrust, no fragments of the augen gneiss have yet been detected in them. This gneiss enters largely into the composition of the conglomerates in the western outliers, and the inference may perhaps be drawn that the augen gneiss, though to a large extent exposed while these western beds were being formed, had subsequently become wholly, or almost wholly, covered by succeeding Old Red Sandstone strata before the upper conglomerates of the Alness and Evanton area were laid down. If this inference be correct, we may conclude that all, or a very large proportion of the schistose area within the map was at one period covered by the Old Red Sandstone.

We shall now proceed to describe the Alness and Evanton area in detail, leaving the outliers for subsequent treatment.

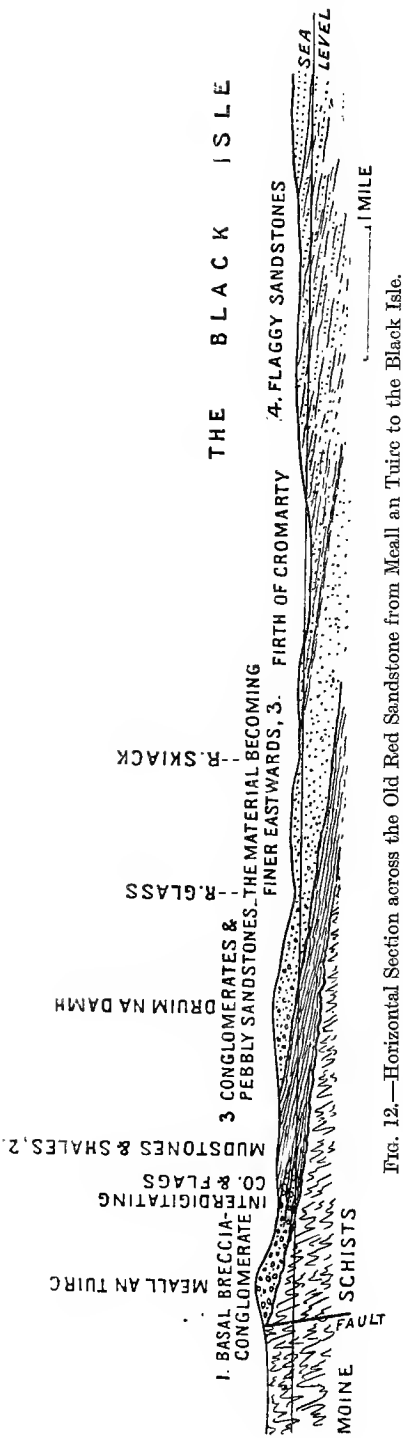

Fig. 12.—Horizontal Section across the Old Red Sandstone from Meall an Tuirc to the Black Isle.

Alness and Evanton Area.

The Old Red Sandstone strata forming the large tract in the south-eastern portion of the map occupy the west side of the Easter Ross syncline (Fig. 12), whose axis passes in a N.N.E. direction through the Black Isle to the coast of the Dornoch Firth. Further to the west they are thrown into a low anticline, the axis of the fold crossing the area in a north-east direction from Tulloch Hill in the south and passing out of the map in the neighbourhood of Aultnamain. To the west of this line the beds dip west and south-west against the metamorphic rocks of the interior.

For a considerable distance along the south-western margin of the area the unaltered sediments rest unconformably upon the schists, but between the Allt nan Caorach and Cnoc Gille Mo Bhrianaig, and again to the north of the Alness River, the boundary between the older and younger rocks appears to be a faulted one.

The available fossil evidence indicates that the whole of the strata within the area under consideration may be included in the Middle or Orcadian Division of the Old Red Sandstone.

The rocks embraced within the area under discussion may be arranged in the following four groups in descending order :—

4. Yellow sandstones, green and red shales, grey shales with nodular limestone bands containing fish remains,—Edderton and Cromarty fish beds.

3. Red and yellow sandstones with scattered pebbles and pebbly bands, passing down into conglomerate with intercalations of sandstone,—Cnoc Fyrish conglomerate.
2. Green and grey shales, flagstones, fetid dark shales and calcareous mudstones;—equivalent to the Strathpeffer "fish beds."
1. Basal breccia and conglomerate.

Lenticular pebbly or conglomeratic beds are also locally developed at several horizons in groups 2 and 4.

The rocks of the highest group occupy the centre of the syncline and form the smooth western slope of the Black Isle. They also appear across the Firth to the north of Alness, and on the extreme margin of the map near Aultnamain Inn. The pebbly sandstones of group 3 form the low ground along the western shore of the Cromarty Firth (Fig. 12), and pass, by the increase of the coarser sediments, into the conglomerates of Cnoc Fyrish, which form the central ridge of high ground between Glen Glass and Druim na Gaoithe.

The shales and flags of group 2 occupy the crest of the anticline, and, rising from beneath the conglomerate of Cnoc Ceislein, extend from Boath through the hollow of Strath Mor, and cover a wide area on either side of the Skiack River.

They are faulted against the conglomerate along the valley of the Alness River at Ardross Castle, and occupy the western margin of the area northwards from that river to Struie Hill, their junction with the metamorphic rocks being also a faulted one.

The basal breccia-conglomerate is locally developed at several points along the margin of the area: *e.g.*, on Cioch Mhor on the north side of Strath Sgiack; between Glen Glass and the Alness River; and on the north side of Struie Hill. It is essentially a shore deposit, laid down upon an oscillating surface in wedge-shaped masses that thin out to the eastward and interdigitate with the finer-grained sediments of group 2.

GROUP 1.—BASAL BRECCIA AND CONGLOMERATE.

The local base of the series is well displayed on the summit and eastern face of Meall an Tuirc, in Glen Glass (Fig 12). It presents the appearance of a coarse breccia-conglomerate—a tumultuous aggregate of angular, subangular and occasionally rounded blocks of metamorphic rock set in a close brick-red matrix.

The included fragments are often as much as 3 or 4 ft. in length, and may all have been derived from the immediately contiguous schistose area, no rocks of distinctly foreign origin having been observed.

It is possible that the junction of the conglomerate with the schists on the west side of the hill is not altogether a natural one, and there are indications of movement along the line of contact. The fault is probably, however, of little magnitude, and the appearances are almost equally compatible with the deposition of the breccia against a steep face of the original land surface.

The Meall an Tuirc conglomerate extends northwards over Bendeallt to Cnoc Gille Mo Bhrianaig, where it contains lenticular partings of red sandstone. The inclination of the beds, which on Meall an

Tuirc appears to be to the N.N.E., is here to the S.E. A similar breccia-conglomerate covers the summit and eastern slopes of Meall an Leathaid, one mile and a quarter north-west of Cnoc Gille Mo Bhrianaig. The sediments are there resting unconformably upon the schists, and show considerable evidence of overlap of the higher beds upon the steep surface of the original floor.

A good example of a locally derived conglomerate is found on Allt Dearg, at a point a mile south-east of Aultnamain Inn. Opposite the crofter's house the stream is cutting a section in a bank of coarse conglomerate, almost entirely composed of rounded and subangular blocks of a red unfoliated biotite granite, set in an arkose matrix formed by the disintegration of the same rock. The material has evidently been derived from the Fearn granite area, whose eastern margin lies two miles to the west. This conglomerate is well stratified, and dips E.S.E. at 15°.

The Fearn granite also enters largely into the composition of the coarse conglomerate seen along the course of the Strathrory River below the bridge, and in the gorge cut by the stream three-quarters of a mile above this point. At the latter locality rounded granite boulders, 3 to 6 ft. and upwards in diameter, are set in a conglomeratic matrix composed of subangular fragments of schist and granite, mostly less than a foot in length.

The great majority of the stones in the conglomerate of Struie Hill, at the northern end of the area, are, on the other hand, formed of the metamorphic rocks of the Moine Series, and only a few small pebbles of unfoliated granite have here been observed, though there are many fragments of coarse muscovite pegmatite and others of a purple felsitic rock.

GROUP 2.—SHALES, FLAGSTONES AND MUDSTONES.

The fine-grained pelitic sediments of this group are best displayed along the courses of the Alness and Skiack Rivers, and Allt nan Caorach. For the convenience of the observer who may visit the ground, the whole stream section will be described continuously in each case, although members of both higher and lower groups are included in parts of the section.

Skiack River Section.

As we ascend the River Skiack from the bridge at Evanton, the stream below and above Milton of Katewell is found to be flowing over yellow sandstones with pebbly bands and scattered pebbles, and occasional intercalations of ripplemarked flagstones.

At a point a quarter of a mile S.S.W. of Upper Park, the stream is crossed by a fault with a downthrow to east, by which these pebbly sandstones of group 3 are brought down against the shales and mudstones of group 2, the latter dipping up-stream in a W.S.W. direction at 20° to 25°. Between Swordale and Fannyfield the course of the stream coincides more or less with the strike of the green and purple mudstones which are seen at intervals along the river bed. Above Fannyfield, where the Skiack is still cutting through the boulder

clay which fills its pre-glacial channel, the stream turns to the north and flows across the strike of the beds, exposing for a short distance sections of green and grey shales (the latter sometimes fetid), mudstones and thin calcareous flagstones, all having an easterly dip. Similar rocks are seen in the small burns which descend the hill-slope south-west of Clare.

The stream now passes for some distance through alluvial flats, until at Bog nam Biast a similar series of rocks is again exposed. The strata are now dipping S.S.E. and S.S.W. at angles of 18° to 35°, and show signs of movement, the grey shales, well seen in the little gorge directly south of Cioch Mhor, being distinctly cleaved. It is probable that a fault, possibly the continuation of the boundary fault seen in the Allt nan Caorach 3¾ miles to the N.N.E. and described in the sequel, here crosses the Skiack valley.

A quarter of a mile above this point the stream flows over a yellow breccia composed of angular fragments of schist up to 18 ins. in length. Reddened siliceous schists of the Moine Series are seen on the hill-slope immediately to the south of the burn, but the relations of the schistose and unaltered sedimentary rocks are not visible in the stream section. On the summit of Cioch Mhor, a mile to the north, the Old Red conglomerate is seen resting unconformably upon an irregular surface of the metamorphic rocks, and the evidence favours the conclusion that the junction along the boundary line to the south of that hill is a natural one.

Sections in the River Glass and Allt nan Caorach.

The lower members of the series are also well displayed along the course of the River Glass above Evanton, and of its principal tributary the Allt nan Caorach. The deep chasm of the Black Rock of Novar has been eroded in the pebbly sandstones and conglomerate of the Cnoc Fyrish group. The sudden sharp bends in the course of the gorge have been determined by cross joints in the rock, while its general direction seems to be independent of any structural line. Micaceous purple and red shales and flagstones of group 2 appear in the river at Redburn, a mile above the entrance to the gorge, and are also seen in the small burn which at this point joins the river on the right bank. There is evidence of considerable disturbance along the tributary stream; the beds are inclined at high angles to the north-west, and a fault, along which issue calcareous springs, brings the purple shales into contact with olive-green shales with calcareous bituminous beds on the south bank.

A third of a mile above the junction of the Allt nan Caorach with the River Glass the former stream is crossed by the belt of coarse breccia-conglomerate which forms the fine waterfall on the main stream known as the Eas a' Chonaisg. Following the course of the Allt nan Caorach, the observer finds the stream flowing for some distance in a deep inaccessible gorge cut through the conglomerate. Near the head of this gorge, and a third of a mile below the ford ¾ mile S. by E. of Eileanach, a fault with a hade down-stream of not more than 50° throws down the coarse tumultuously arranged breccia-conglomerate (containing angular schist fragments 2 and 3 ft. in length) against a series of grey shales with bands of grey calcareous grit. The

shales are crushed and cleaved near the fault (Fig. 13, p. 147), while the cleavage planes, which are parallel to the line of movement, do not pass through the harder grit bands.

Above the ford follows a long series of grey and purplish micaceous flagstones with shaly partings, with a westerly dip (W. 15° S. to W. 15° N.) at angles of 16° to 35°. A third of a mile west of the ford, intercalated bands of pebbly conglomerate begin to appear among the flagstones and thicken westwards, until, at the point where a waterfall and natural rock arch are seen, the rock is almost entirely a conglomerate, composed of medium-sized rounded and subangular stones set in a grey matrix. This conglomerate is less coarse and shows a far more regular arrangement of its components than the breccia lower down the stream. Near the boundary fault which crosses the stream about 600 yds. further west it contains some very large blocks of schist and pegmatite, and finally a hard grey breccia, made up of angular fragments of the adjacent schists, is brought against crushed and brecciated siliceous schists of the Moine Series.

Alness River Section.

The third section to be described is that seen along the picturesque gorge of the Alness River between the foot of the Strath Rusdale stream and the village of Alness. The higher part of the river valley has been determined by the Loch Morie fault, which passes into the Old Red Sandstone area two miles below Loch Morie, and throws down the Cnoc Fyrish conglomerate to the south against the flags and shales of group 2 for a distance of two miles and a half east from Loanroidge. There are marked signs of movement along this line of dislocation; the shales and flagstones are vertical or inclined at high angles, and often show cleavage, crushing and induration.

An interval of 250 yds. separates the last place where the siliceous Moine schists are seen in the river from the first appearance of the shales on the north side of the stream under Inchlumpie Wood, half a mile below the junction of the streams. Evidence obtained further to the north indicates, however, that the boundary between the two formations is a fault.

At this point shales with thin beds of hard flagstone are dipping S.S.W. at 40°. The shales are well cleaved, the planes of cleavage making an angle of 60° with the bedding. The conglomerate on the downthrow side of the fault is seen at the next bend higher up, on the opposite side of the river. Similar sections of cleaved and crushed shales with bands of hard calcareous grit and flagstone, either vertical or with a south-west or southerly dip at high or moderate angles, are seen at many points along the stream both above and below Ardross Castle, while the conglomerate appears on the south bank wherever the river has cut back to the line of fault.

Between Dalreoch and Cuillich, rather more than a mile below the Castle, the shales are succeeded on the left-hand bank by the pebbly conglomerates and red and white pebbly sandstones of the Cnoc Fyrish group, through which the river flows in a winding gorge, with steep bluffs of conglomerate at the head of each bend, to the bridge at Alness. L. W. H.

The basin-shaped valley of Boath, opposite the mouth of Strath

Rusdale, has been carved out of the softer strata of group 2, which intervene between the conglomerates of Meall an Leathaid and of An Corran. Soft red and purple flaggy sandstones, green and purple mudstones and dark shales are seen in the three burns which converge below Boathmore, and join the Alness River near Knocklea. The beds have a general westerly to north-westerly dip at angles varying from 5° to 30°, and strike against the Loch Morie fault, which throws them down against the schists between Loanroidge and Knocklea.

C. B. C.

Similar rocks are exposed in the Tollie Burn, a mile to the north of Ardross Castle, dipping S.S.W. at 30° to 45°, and striking against the boundary fault. The actual junction with the schists is obscured, but a small thickness of conglomerate appears to intervene between the mudstones and the older rocks. The relations of these sediments to the metamorphic rocks can, however, be studied in the Allt Muighbhlaraidh, three-quarters of a mile N.N.W. of Aultnamain Inn. At a point a third of a mile above the bridge, where this stream is crossed by the Bonar Bridge road, purple and greenish shales with bands of micaceous flagstone, dipping S.S.E. at high angles, are seen in faulted conjunction with crushed and purple-stained siliceous Moine schists.

The shales as they approach the fault are often well cleaved, and a short distance below the bridge show minute overfolding or puckering, the axes of the folds being approximately parallel to the general course of the boundary fault.

GROUP 3.—RED AND YELLOW SANDSTONES AND CONGLOMERATES.

An almost continuous section of the pebbly sandstones of group 3 is exposed along the western shore of the Cromarty Firth between Evanton and the southern margin of the map. Below Mountgerald the old coast-line is indicated by a low cliff of conglomerate with intercalated and inconstant bands of grey laminated sandstone. The pebbles are well rounded, and range generally from 1 to 8 in. in length, but include some large blocks of siliceous schist which lie, as if dropped in, at angles to the bedding planes. The stream which flows from Woodlands into the sea at the old chapel passes over an alternating series of yellow sandstones and bands of conglomerate, the latter giving rise to three waterfalls below the bridge. Sandstones with frequent conglomeratic bands continue northwards to Foulis Point, where the conglomerates disappear, and false-bedded yellow, red and white sandstones with nests and irregular layers of pebbles and seams of green shale occupy the shore as far as the church of Kiltearn, at the mouth of the Skiack River.

The lower course of that stream affords another good section of these pebbly sandstones, succeeded by the flags and shales of group 2. This section is discussed in an earlier paragraph (p. 134).

Excellent sections of the Cnoc Fyrish conglomeratic series are exposed in the deep ravine cut by the Big Burn between Cnoc Fyrish and Creag Ruadh. Thick beds of pebbly conglomerate are here intercalated with bands, 10 to 12 ft. in thickness, of yellow sandstone, containing a few scattered pebbles. The conglomerate is composed of pebbles, usually well rounded, set in a tough yellow sandy matrix. The larger fragments rarely exceed nine inches in greatest diameter,

while the majority are less than two inches in length. The bulk of the pebbles are derived from the crystalline schists, those of quartzite or siliceous granulite predominating. There are also many of unfoliated red granite and pegmatite, which may have been derived from the Newer Granite area six miles to the north. Among those to which a more distant origin may be definitely assigned are fragments belonging to recognisable zones of the Durness Limestone; dolomite shales resembling those of the "Fucoid Beds"; and Torridonian grits and sandstones in fair abundance. One or two examples of a much decomposed porphyrite have also been observed.

A closely similar assemblage of pebbles is found in the conglomerate along the course of the Alness River between Dalreoch and the village of Alness, the fragments of Durness Limestone and Torridon Sandstone being perhaps more numerous than in the locality last described. Many pebbles of Durness Limestone, up to four inches in length, occur also in the conglomerate near Stittenham, along the upper part of the stream that flows into Loch Achnacloich. The occurrence of Durness Limestone pebbles in these conglomerates was first noted by Mr. Hugh Miller in the year 1887.

The entire absence from the upper conglomerate of boulders of the augen gneiss, which enter so largely into the composition of the basal breccias to the west and south-west, and the inference drawn from this difference of composition, have been already referred to near the beginning of this chapter.

GROUP 4.—SANDSTONES WITH THIN SHALES AND MARLS.

The highest members of this division of the Old Red Sandstone that come within the map occupy the smooth drift-covered slopes of the Black Isle, where inland sections are rarely seen. The rocks are, however, well exposed along the eastern shore of the Firth between Findon Mains and Alnessferry. They include fissile and flaggy sandstones, generally yellow, but sometimes grey or reddish in colour, with pebbly bands, pebbly nests and scattered pebbles, clay galls and thin seams of greenish shale and red marl. Intercalated with the sandstones, half a mile south of Cullicudden, is a band, 12 to 15 ft. thick, of shale containing fragments of *Psilophyton*, also nodules and layers of pale brown impure limestone, and calcareous yellow flagstones.

Opposite Foulis the strata are nearly horizontal, but further to the north and opposite Alness Point they dip to the east at 8° to 15°. The strike of the beds at this point carries them across the Cromarty Firth to the north of Alness, where the yellow sandstones and *Psilophyton* shales are seen half a mile E.S.E. of Achandunie, and along the southern slope of Cnoc Navie Wood. An excellent section of these sandstones and shales, with abundant plant remains, is exposed in a small burn which falls into the Strathrory River on the right bank, just outside the limits of this map.

The rocks of this group pass out of the map a little to the south of Strathrory, but reappear further to the north, on the west side of the anticline, between Blackpark and Aultnamain, where they dip to the north-west, and are thrown down against the shales and mud-

stones of group 2 by the fault which runs N.N.E. a little to the west of Polinturk.

An excellent section of the calcareous beds of this series is exposed in the Allt Muigh-bhlaraidh at Blackpark, on the extreme margin of the map, and is given below in descending order.

	Ft.
6. Yellow calcareous sandstone. Soft, dark purple and red sandstones. Red marly shale with courses of red sandstone	5
5. Flaggy yellow and calcareous sandstones with suncracks.. ..	1–3
4. Greenish shales with plant remains, and irregular layers of impure limestone	1
3. Dark grey and greenish calcareous shales with nodular layers of limestone. Fish scales and plant remains abundant in the shales, and fish well preserved in the nodules, especially in the upper part of the bed	6
2. Greenish shales with courses of limestone and impure calcareous sandstone	3
1. Yellow calcareous sandstone and purple shales	6

A series of specimens (a list of which will be found in Appendix I.) collected from this locality by Mr. Tait, has been submitted to Dr. Traquair, who identifies them with specimens from the Cromarty fish bed, thus establishing the Middle Old Red Sandstone age of the rocks of this area. This section has long been known as a productive locality for ichthyolites, which are well preserved in flattened nodules of grey limestone. They were first described in 1861 by the Rev. J. M. Joass, in a letter communicated to the London Geological Society by Sir R. I. Murchison.* L. W. H.

The Western Outliers.

The large Strath Rannoch outlier appears to have been first described by Mr. William Morrison, of Dingwall.† It was no doubt referred to, together with various other adjacent outliers, by Mr. W. Gunn ‡ about ten years subsequently. The rocks included in this outlier are well seen, and consist of conglomerates, sandstones and mudstones with thin calcareous bands. No regular order of succession has been made out, and the relation of the conglomerates to the other sediments is an irregular one. Conglomerate occurs high up on the flanks of Meall nam Mullach, while the fine-grained sediments appear in the valley below.

Such an arrangement may possibly in certain cases indicate a lateral passage of the fine sediments into the coarser towards the shore line then existing rather than a superposition of the conglomerates. But in other cases it is probable that the coarse conglomerates are superposed on finer beds. For instance, near the head of the burn south of Carn Loch nan Amhaichean, where the beds dip westward, down-stream, faster than the fall of the stream, a coarse boulder bed, formed chiefly of great blocks of augen gneiss, lies west of, and apparently stratigraphically above, certain finer conglomerates.

* *Quart. Jour. Geol. Soc.*, 1861, vol. xvii. p. 553.

† 'A Minor Basin of the Old Red Sandstone in Mid Ross,' *Trans. Edin. Geol. Soc.*, 1886, vol. v. p. 331; also, 'An Outlier or Minor Basin of Old Red Sandstone in Mid Ross-shire,' *Trans. Edin. Geol. Soc.*, 1891, vol. vi. p. 188.

‡ *Annual Report of the Geological Survey* for the year 1896, p. 53.

It is also the case that in this locality the coarse conglomerate lies further away from the probable margin of the schist than do the finer conglomerates on the east. In these finer conglomerates pebbles of siliceous Moine schist are much more common than those of augen gneiss, and in one place a pebble of mica trap was detected. The finer conglomerates in different parts of the burn perhaps occupy considerably different stratigraphical horizons. In the conglomerates in the lower part, the larger pebbles, often several inches long, are almost entirely composed of siliceous schist or of vein-quartz, but the finer ingredients comprise many grains of opalescent quartz and red felspar, both of which have probably been derived from the augen gneiss.

It is possible that the conglomerates last referred to are separated from the coarse conglomerate of augen gneiss on its south-east side by a powerful fault striking north-east. No fault is actually exposed where the fault suggested is mapped across the burn, but the schists along the continuation of this line appear to have been affected by a powerful fault or lateral wrench (see Chapter IX.). It is not certain, however, that any part of this fault is newer than the Old Red Sandstone.

A conglomerate near Creag Bhreac Mhor, on the west side of Strath Rannoch, forms a series of fine escarpments, the most northerly of which has an apparent dip to the south. To the north-east of the same hill red sandstones appear, dipping south-east at 20° to 30°, and similar rocks with a north-west and west dip are exposed along the Strath Rannoch stream. An interesting section of the sandstone and mudstone series is exposed in the more northerly of the two small burns which flow off the north-eastern slope of Creag Bhreac Mhor. In the upper part of this stream red sandstones dip south-east beneath the soft purple mudstones which are well exposed further down the stream. The mudstones contain hard greenish lenticles which lie along the planes of bedding. These latter are, however, distinctly crossed by a more prominent set of planes due to cleavage. The cleavage dips N.W. or N.N.W. at a high angle, while the bedding is gently inclined to the south-east.

The finer sediments, including sandstones and mudstones with numerous bands of calcareous sandstone and thin limestones, are also well seen along the course of the Allt a' Choire-rainich, where the dip is generally in a north-westerly direction. A rough cleavage, conformable in angle and direction to that described in the preceding paragraph, has been observed in the sandstones a little to the north-east of the keeper's house in Strath Rannoch.

On the hillside a quarter of a mile south-east of the above house, a calcareous conglomerate contains many fragments of felspar which have no doubt been derived from the augen gneiss. The thickness exposed is about 12 ft., and certain lenticular bands, each about four inches thick, are much more calcareous than the rest. A specimen from one of these stripes (10915) has been sliced and examined by Dr. Flett, who states that the calcite does not appear to be detrital, but is perhaps a chemical deposit. It encloses a few shreds of fossil wood.

The northern boundary of this outlier is fairly distinct between the Strath Vaich River, above Lubriach, and Meallan Donn. The

junction of the conglomerate with the schists is visible on the south-west side of that hill, where it rests upon an irregular surface of the older rock. Where this boundary crosses the Strath Rannoch Burn, at a point about three-quarters of a mile south-west of Carn nan Aighean, the section shows an Old Red Sandstone breccia, mainly composed of large blocks of siliceous schist, banked up against a slightly overhanging cliff of similar schist: some of the blocks are as much as 18 ft. long.

The outlier capping the summit of Meall a' Ghrianain, 2531 ft., is probably the highest ground reached by the Old Red Sandstone formation in the North of Scotland. There is present here a thickness of probably 400 or 500 ft. of conglomerate made up almost entirely of huge rounded blocks of augen gneiss many feet in length. In several places blocks as much as 21 ft. in length have been observed, and, to account for their transport, glacial action has been suggested by more than one observer. A few fragments of schist are also embedded on the east side of the hill. The dip of the mass can rarely be ascertained, but a bed of sandstone, only a foot thick, on the western face of the hill, shows a dip to south or south-east. Comparatively little of the rock is actually seen *in situ*, the greater part of the area being covered by loose blocks and disintegrated débris of augen gneiss.

On the eastern side, particularly at its northern end, the underlying surface of the schist is of a very irregular character. If we combine the evidence obtained from the outlier with that from Strath Rannoch, we obtain proof of an alteration of the base level of the Old Red Sandstone to an extent of nearly 1000 ft. in the distance of a mile. On the western side of the outlier, various small isolated exposures of breccia, chiefly composed of angular pieces of siliceous schist, rest on, or in chinks in reddened schist. These breccias are probably local basement beds of the Old Red Sandstone. One of them occurs at an elevation of less than 1500 ft., and its base is inclining westward towards the valley of Strath Vaich. It seems probable, therefore, that the valleys of Strath Rannoch and Strath Vaich were both roughly shaped even in the Old Red Sandstone period, and, after being filled up by deposits belonging to this period, have been brought into existence again by further denudation, which has taken out the comparatively soft Old Red Sandstone strata more quickly than the Moine schists.

A very small patch of conglomerate, which rests upon the augen gneiss at the side of the path leading from the school at the foot of Strath Vaich to Strath Rannoch, is also made up of blocks of augen gneiss. A few hundred yards west of this patch is another larger outlier which appears to rest on the augen gneiss, while on the north it seems to be bounded by a fault with a downthrow to the south. The rock here is not so coarse as in the crags above, and much of it is a pebbly or brecciated sandstone dipping about N.N.W.

W. G., C. T. C., E. M. A.

The irregular nature of the surface on which the Old Red Sandstone was deposited is also shown by the two outliers to the south which cover the tops of Beinn nan Cabag and Beinn a' Bhric, between

the Glascarnoch River and Loch Luichart. On the former hill the conglomerate appears to have been deposited against a steep cliff of augen gneiss, an outlying sill of which forms the western side of the mountain, and large blocks of the igneous rock enter into the composition of the breccia-conglomerate at this point. The Beinn a' Bhric outlier rests partly upon this outcrop of augen gneiss and partly upon the Moine schists, and is composed of conglomerate, almost entirely made up of subangular blocks of siliceous schist, with a few layers of red sandstone.

Several small patches of conglomerate seen resting upon the schist and augen gneiss, between Beinn nan Cabag and Creag Bhreac Mhor, point to the former continuity of these deposits over the intervening areas, from which they have since been removed by denudation.

B. N. P.

The most northerly of these outliers is found near the head of Strath Rannoch, and lies on the north-western slopes of Carn nan Aighean at a distance of a quarter of a mile from the cairn. Like the Meall a' Ghrianain mass it consists of enormous boulders of augen gneiss, with only enough of matrix to fill the hollows between the blocks. One of these blocks was found to measure at least 27 ft. in length. The breccia is resting on the schists at the south-west end of the outlier, but probably extends over some of the augen gneiss in the other direction. Its actual junction with the underlying rocks is, however, nowhere clearly seen.

C. B. C.

CHAPTER IX.

FAULTS.

In this chapter it is only intended to describe a few of the more important faults. The thrust planes, which are accompanied with a development of foliation, have been already dealt with in previous chapters, and will not be further referred to.

Strathconan Fault.

A powerful N.N.E. fault is seen near the head of Loch Luichart, in the stream S.S.E. of Mossford, and again in various other sections near Lochluichart Lodge: the planes of crush are generally nearly vertical. It is certain that near the head of the loch the fault must be accompanied with considerable displacement, for the siliceous schist on the west is impregnated with multitudes of thin veins of foliated granitic material, while on the east side such veins are seldom seen until we go some miles further north. This fault is no doubt the same as the Strathconan fault further south-west, and it is believed that it proceeds in a general south-west direction as far as Loch Hourn, on the west coast of Inverness-shire, but part of the intermediate area between Strathconan and Loch Hourn has not yet been mapped. In the valley of the Meig, in one-inch maps 82 and 83, the slickensides along the fault are often horizontal,* and it is hence believed that the chief movement along the fault has been a horizontal wrench.

Excepting for the exposures near Loch Luichart, the evidence for the fault in the southern and central parts of the map is generally of an unsatisfactory character, the rocks along the supposed line being to a large extent drift-covered. A broad zone of crush in Glascarnoch River, two-thirds of a mile below Aultguish Inn, is perhaps a branch from the Loch Luichart fault, but it is described again under a different heading, with the Coire Mor and Strath Vaich faults. South-east of Carn Loch nan Amhaichean, the presence of a fault, striking in the direction of the Loch Luichart fault, is indicated by some crush breccias in the siliceous granulites of the Moine series. A little further to the east it shifts the margin of the foliated granite, together with a narrow zone of pelitic material which accompanies it, for rather less than a mile. It seems probable that this distance forms a more or less rough indication of the actual horizontal displacement in this area, the south-east side being shifted towards the north-east, as is usual in other districts.

South of Carn Loch nan Amhaichean the fault line is drawn on the map as if it went through the Old Red Sandstone. It cannot be said with confidence that the fault affects this formation, but it is possible

* *Summary of Progress of the Geological Survey* for 1904, p. 79.

that it does so, there being an obscure gap along which it may pass without being anywhere exposed. B. N. P., E. M. A.

In the stream half a mile slightly north of east of the Ordnance Station 2076 on Leaba Bhaltair, a crush, one or two feet thick, strikes slightly west of north and inclines west. This probably continues north, and bounds the eastern side of the mass of hornblende schist which is shown in the map on the N.N.E. side of Leaba Bhaltair. Near the northern end of this side a crush is seen inclining west, and between this crush and the hornblende schist there is an obscure gap, about 20 yds. wide, in which more crushed material may occur. This fault must twice cross the burn W.S.W. of Carn Dubh, and separates a mass of diorite and hornblende schist on the east side from the Moine schists on the west. Thence it proceeds in several branches along the west side of Cnoc na Tuppat, where the total displacement of the outcrops, the east side towards the north, is about a mile. The branches on this hillside occasionally make considerable angles with one another, but their general direction is nearly north and south. The fault rock is sometimes highly impregnated with siliceous material.

The northerly continuations of the Cnoc na Tuppat faults are exposed in the south bank of the River Carron, close to the foot of Glen Calvie. One of them is represented by a band of crushed material, seven or eight yards wide, which inclines westward. Another thinner almost parallel crush, a little to the eastward, inclines east. West of the wide crush just referred to is another, of considerable width, which seems to strike S.S.W. Perhaps this forms the eastern boundary of a rather broad band of pelitic schist which has been mapped in this locality.

Still further west, a fault striking S.S.W. breaks the pelitic band and displaces the outcrop for rather more than a quarter of a mile, in the same direction as the Cnoc na Tuppat faults.

Coire Mor and Strath Vaich Faults.

The main line of crush is well seen in the straight part of Allt a' Choire Mhoir near the 1250-foot contour. Its strike in this locality is north-west, and the inclination at a rather low angle towards the south-west, the direction of downthrow indicated by the displacement effected in the adjacent crops of schist. The base of the broad zone of pelitic schist is displaced about half a mile, the south-west side towards the north-west. The top of this zone is less well defined than the base, and the displacement effected in it cannot be calculated so confidently, but it appears to be about 500 yds. A hard rib of fault rock is exposed, of compact character with close parallel crush planes welded together into one block: below this, the pelitic schist has been crushed into small phacoids with their long axes inclined parallel to the hard rib.

Nearly three-quarters of a mile N.N.E. of Loch Sruban Beaga the fault divides. One branch, which itself probably subdivides a little further south-east, is seen to be four or five yards wide at the head of the rather straight stream, a little below the 2250-foot contour. On the hill-top S.S.E. of this exposure much shattered and brecciated siliceous schist is seen, partly *in situ* and partly in the form of loose blocks. Some other branches of the fault are also seen a few hundred

yards west of the shattered and brecciated area just referred to. In the crags of Cail Mhor the positions of the two main crushes are rather more than a third of a mile apart: of these the crush lying furthest west is represented in one place by a vertical breccia about three feet wide, while the other, which is exposed at the head of a landslip, inclines south-west. The latter branch is indicated again by exposures of crushed rock on the high ground west of Meall a' Chaoruinn.

Various crushes can be traced in Strath Vaich between the head of Loch Toll a' Mhuic and the mouth of the glen. Near the foot of the loch crushes are seen not only close to the east side of the loch but also on the hillside between 250 and 400 yds. further east. They strike nearly north and south, and probably represent continuations of some of the crushes already referred to, though it is to be noted that some of them are inclined eastwards. On the east side of the burn about a third of a mile north of the Lodge, the chief area in which crushes occur is nearly 100 yds. broad, but certain other crushes lie a little further to the west.

A series of steep or vertical crushes striking about north and south crosses Glascarnoch River about two-thirds of a mile below Aultguish Inn. It is probable that they represent continuations of the Strath Vaich crushes, and that they are near the junction of these with another powerful fault, the Strathconan fault, which has been already described. C. T. C.

Loch Morie Fault.

This fault has been traced from near Dalreoch, on the Alness River, in a W.N.W. direction, up the course of the valley and Loch Morie into the Carn Chuinneag granite, in which its course has been followed nearly as far as Mullach Coire na Gaoitheag. Its course, within the Old Red Sandstone, is described on pp. 136, 147. At Balmeanoch, further west, it bounds the Old Red Sandstone, throwing down the mudstones to the south against the Moine schists for a distance of a mile.

Still further up the valley it truncates the main band of pelitic schist, and throws the crop on the south side a distance of two miles further west. It makes a considerable mark in the cliffs on the north shore of the lower part of Loch Morie, and then crosses this loch and passes to the south of Meall nam Bo, beyond which it throws the eastern boundary of the granite, together with the marginal band of hornfels and mica schist, for a distance of more than a mile, in the same direction as the great pelitic band further east.

It enters the granite on the south-east flank of Meall a' Chaoruinn, and can be traced within it for about a mile, shifting the coarse marginal band of augen gneiss for nearly a mile, the south-west side towards the north-west.

A branch, given off from this fault at the north-west end of Loch Morie, passes on the north side of Meall nam Bo, and towards the burn which drains Lochan Lice. It makes a good feature on the northern flanks of Meall nam Bo, and shifts both the hornfels and augen gneiss in the same direction as the main fault. C. B. C.

Nearly Horizontal Crush Plane in Strath Vaich.

In Strath Vaich River, about 100 yds. below the foot of Allt Glas Toll Mor, the siliceous schist is crossed by a slickensided crush plane which is nearly horizontal, having only a very gentle inclination in a W.N.W. direction. The plane shows distinct brecciation, and the foliation planes of the adjacent schist are considerably twisted, but there are no means of finding the amount of displacement effected.

C. T. C.

Faults in the Alness and Evanton Area.

The faulted relation of the sedimentary and metamorphic rocks along the western boundary of the Old Red Sandstone area between Struie and the Alness River, is indicated by the absence of the basal conglomerate and the nature of the junction of the shales and mudstones with the schistose rocks in the few places where the line of contact can be observed.

In the Allt Muigh-bhlaraidh, 500 yds. west of the public road, flags and shales, dipping at high angles, are faulted against crushed and stained siliceous rocks. Similar phenomena are seen where the boundary line crosses a tributary burn a mile further to the south. In the Tollie Burn, on the east side of Cnoc an t-Sithein Beag, the crushed schists appear to be actually in contact with a bed of conglomerate, but this is succeeded, a very short distance down the stream, by mudstones and shales dipping at 45° and striking against the fault line. The approximate position of the fault along the smooth drift-covered hill-slopes between the streams, can only be inferred from slight changes in feature and from springs thrown off along the line of junction.

The exact relations of the Old Red Sandstone and schistose rocks are not seen in the Alness River, but cleaved grey shales are visible on the north side of the stream in Inchlumpie Wood, 250 yds. below the first exposure of schist in the river bed.

The boundary fault appears to be truncated by the powerful east and west dislocation (the Loch Morie fault) which passes down the Alness River, and there is no evidence of its passage through the shale and mudstone area that occupies the hollow of Boath. Between the southern slopes of Meall an Leathaid and the Allt nan Caorach the Old Red Sandstone area is again bounded by a fault, the shales and mudstones and the basal conglomerate being in turn brought against the schists on the north side of Cnoc Gille Mo Bhrianaig. Further to the south the fault appears to diminish, and to the west of Meall an Tuirc is, as already mentioned on p. 133, probably of little magnitude.

The boundary fault is well seen where it crosses the Allt nan Caorach at a point three-quarters of a mile east of the junction of that stream with the Allt Coire Misirich, bringing a locally derived breccia into contact with crushed metamorphic rocks of the Moine Series.

To the south of the Allt nan Caorach this fault either dies out or passes into the Old Red Sandstone, as from the summit of Cnoc nan Each to the southern margin of the Sheet the junction of the conglomerate with the underlying schists is a natural one. It is possible that the line of movement which crosses Strath Skiack at Bog nam Biast may be a continuation of the above mentioned fault.

The cleavage of the shales where they are affected by the faults that traverse the Old Red Sandstone area has already been referred to in the description of the various river sections (Chapter VIII.). Attention may, however, be once more called to the particularly well developed cleavage seen in the shales that are faulted against the conglomerate in the Allt nan Caorach (Fig. 13), half a mile south-east of Eileanach. In the immediate vicinity of the fault the grey shales are closely cleaved, the cleavage planes being distinctly parallel to the plane of movement. As the shales are followed up stream, away from the fault, the cleavage gradually disappears. The natural inference from these facts is, that the cleavage of the shales, the softer and finer-grained rocks of the series, is due, both here and at the other localities mentioned, to the crustal movements that produced the faulting of the strata.

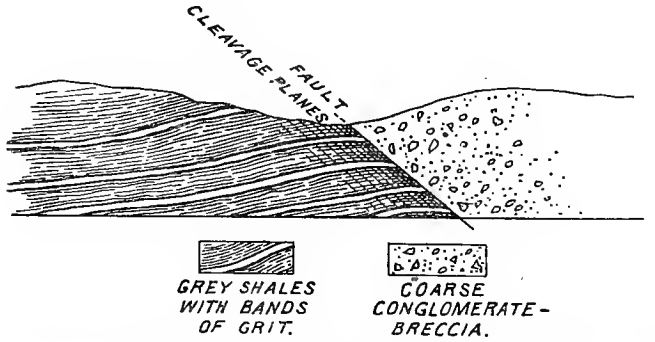

Fig. 13.—Diagrammatic Section showing Cleaved Shales in the Old Red Sandstone. Allt nan Caorach, west of Evanton.

The Loch Morie fault first touches the Old Red Sandstone rocks near Ballavoulen, about two miles below the foot of Loch Morie, and follows the course of the Alness River eastwards as far as Dalreoch. Beyond that point its position is uncertain. Between Ballavoulen and Loanroidge the fault bounds the sedimentary area, throwing down the shales and mudstones of Boath against the metamorphic rocks which are seen in the bed of the Alness River. At Loanroidge it enters the Old Red Sandstone, and brings the shales and mudstones on the north side of the stream into contact with the Cnoc Fyrish conglomerate (group 3) on the south. A short distance below Dalreoch conglomerate and sandstone appear on both sides of the river, and the further extent of the fault is conjectural.

The evidence as to the position of the fault in the Alness valley, and the effect on the strata along the line of movement, have already been discussed in the description of the Alness River section (Chapter VIII.). L. W. H.

Faults in the Old Red Sandstone near Strath Rannoch.

Several small faults are seen to cut the Old Red sediments along the course of Allt a' Choire-rainich, north-east of Strathrannoch house. Most of these faults run in a north-westerly direction, and those of

this class have the peculiarity of being almost vertical in hade, while the slickensiding along them is nearly horizontal. A few of the faults follow other directions. Near one of these which has a north-easterly trend, a very close jointing, resembling cleavage, has been developed in the sandstone, parallel to the fault, and dipping to the north-west at an angle of 70°. E. M. A.

CHAPTER X.

PLEISTOCENE AND RECENT.

Glaciation and Glacial Deposits.

In describing the glacial phenomena observed, it has been found convenient to divide the map into two areas, one including the north eastern, central and southern parts, and the other the north-western and northern. The dividing line between these two areas is taken roughly from Kincardine, near the north-east corner of the map, through Carn Chuinneag to Meall a' Ghrianain, and thence westwards. The north-eastern, central and southern area is much larger than the other, and will be described first.

NORTH-EASTERN, CENTRAL AND SOUTHERN AREA.

Most of the glacial phenomena observed in the north-eastern, central and southern portions of the map appear to be due to ice moving outwards across the Sheet in a direction lying generally between E.N.E. and E.S.E., but modified locally by variations in surface relief and other causes. The date of origin of the greater part of these phenomena may be assigned to a phase somewhat later than that of the maximum glaciation, when large confluent glaciers, issuing from mountain glens and corries far to the west, poured in an unbroken sheet over the lower hills of Central and Easter Ross.

Traces of an earlier and more universal glaciation are rare, and chiefly confined to a small area on the south-eastern seaboard. The last phase of independent valley glaciers has, however, left evidence of the later ice-movements in many parts of the area.

The evidence bearing out the statements made above will now be discussed in detail. L. W. H.

Direction of Glaciation.

An examination of the striæ observed in the north-eastern and central parts of the map points to a general easterly movement of the ice over the greater part of the area.

In the extreme north-east, between Kincardine and Struie Hill, the striæ have a general E.S.E. trend, with local variations to due east. Further to the south-west, on Meall na h-Uigeig, and between the heads of the Easter and Wester Fearn Burns, they point E. 20° N.

Additional evidence of this change in direction is afforded by the erratic blocks which have been carried into the tract referred to. Among these we find not only boulders of augen gneiss but also others of hornfels with large chiastolite crystals, of the type occurring on

Meall a' Chaoruinn and Beinn nan Eun, about 9 and 12 miles respectively further south-west.

In the central region, the coarse augen gneiss which forms the flat summit of Carn Sonraichte, N.N.W. of Kildermorie, is beautifully ice-polished, and has retained the deep grooves and scratches cut by ice moving due east, the direction of movement being confirmed by the smoothed western and north-western faces of the projecting rock masses, in contrast to the opposite faces, which are more or less rugged and broken up. On Am Mam and Cnoc a' Mhadaidh, on either side of Strath Rusdale, the striæ run E. 30° S. Those striæ which indicate a considerable divergence to the north and south of east, are found at a comparatively low altitude, and probably originated at a later period, when the surface-configuration (of the ground) began to reassert itself, and the mass of high ground around Beinn Tharsuinn caused a divergence of the ice, northwards towards the Dornoch Firth, and southwards into Strath Rusdale and the valley of the Alness River.

W. G., C. B. C.

The E.S.E. striæ on the lower ground near Kincardine were probably produced by ice moving out of Strath Oykel, down the Kyle of Sutherland.

The high-level striæ found in the country to the west of the Wyvis range, between Loch Luichart and Loch Glass, repeat the evidence of an easterly (E. 10° N.-E. 30° S.) ice-carry.

Much of the ground is covered with peat or drift, but ice-markings are visible on Carn Mor and the Queen's Cairn; in the deep hollow between An Cabar and Little Wyvis, and on the summit of Creagan an Eich Ghlais and the hills overlooking Loch Luichart.

Those found at lower levels in the valleys of the Black Water and the Conan, and between Corriemoillie and Garve, are evidently due to the later valley glaciers and follow the trend of the glens. High-level local striæ are seen in several of the corries of Ben Wyvis, and point out of the corrie in different directions. L. W. H.

Erratic Blocks.

The distribution of the boulders of so easily recognisable a rock as the foliated Inchbae granite or augen gneiss affords a weight of evidence, in addition to that supplied by the striæ, as to the direction of ice-movement during the various phases of the glacial period. These boulders attracted attention many years ago, and among the earlier writers who referred to them may be mentioned Hugh Miller,* Professor Nicol,† Mr. William Jolly,‡ Mr. T. D. Wallace,§ and Mr. W. Morrison.‖

* 'Rambles of a Geologist.' It is not clear, however, that the writer knew the source of the boulders.

† 'The Geology and Scenery of the North of Scotland,' Edin., 1866, p. 70.

‡ 'Notes by William Jolly, Esq., Inverness, on the Transportation of Rocks found on the South Shores of the Moray Firth.' Printed in the Fifth Report of the Boulder Committee of the Royal Society of Edinburgh, *Proc. Roy. Soc. Edin.*, 1878–1879, vol. x. p. 178. Notes printed in the Sixth Report of the above Committee, *Proc. Roy. Soc. Edin.*, vol. x. p. 620.

§ Notes printed in the Sixth Report of the Boulder Committee of the Royal Society of Edinburgh, *Proc. Roy. Soc. Edin.*, vol. x. p. 623.

‖ Notes printed in Report of the Boulder Committee of the Royal Society of Edinburgh, *Proc. Roy. Soc. Edin.*, 1880–1881, vol. xi. p. 756.

The granite masses from which most of these boulders must have been derived extend across the map in a N.N.E. and S.S.W. line, from Carn Bhren in the north to Loch Luichart in the south, and nearly reach the margins of the map in both directions. Boulders have, however, no doubt, also been carried from the outlier of Old Red Sandstone conglomerate on Meall a' Ghrianain, which lies a little west of any augen gneiss *in situ*. Except on the higher parts of Ben Wyvis, augen gneiss boulders are found over the whole of the country included in that portion of the map which lies to the east of these granite masses. They occur at all levels up to 2250 ft., on the great mass of Beinn Tharsuinn north of Strath Rusdale, and to 2400 ft., on Meall Mor, which forms the watershed between Loch Morie and Loch Glass. Their size is sometimes very large, and they are in consequence frequently used as landmarks. As examples of the larger ones we may mention one, measuring 30 ft. × 18 ft. × 15 ft., which occurs half a mile east of Loch Magharaidh, in the Kildermorie Forest, and another, measuring 21 ft. × 15 ft. × 15 ft., near Braeantra, in Strath Rusdale.

To the south, east and west these augen gneiss boulders have been recognised far beyond the limits of the map being described. In one-inch map 83, to the south, the southern limit of distribution passes from Loch Luichart to the Beauly Firth, and crosses the River Orrin about a mile above its junction with the Conan. To the east the boulders are common over the whole country between the Beauly and Dornoch Firths, and have been reported along the coast as far east as Buckie.* C. B. C.

Large boulders of augen gneiss, some of which are from 15 to 18 ft. in length, derived from the conglomerate of Meall a' Ghrianain, occur to the west, south and east of that hill; while others have been carried south-westwards across the Strath Vaich valley on to the higher ground to the west. These boulders are abundant in the lower half of the burn which runs westward past Lubachlaggan, but they have not been observed in the higher half, and there is no indication that the carry from the northern part of the conglomerate was at any period northward. On the west side of Strath Vaich the boulders are plentiful in the valley of Allt Coir' a' Chliabhain, but not further northward. Boulders of the same rock are plentiful in the moraines along the roadside between Aultguish and the western margin of the map, and a large group may be seen on the hillside north-west of Loch Droma, just outside the limits of the map, while large blocks were observed by Mr. Gunn still further to the west in the valley of the Broom † (Fig. 14).

The disposition of the moraines and the nature of the material along the upper part of the Glascarnoch valley show that they were laid down by ice travelling eastwards, from Beinn Dearg in the north and the Fannich Hills in the south. Many of the augen gneiss boulders referred to above may therefore have been originally borne westwards by the ice during the period of maximum glaciation, and subsequently carried eastwards and redistributed by the glaciers of a later period.

The lowness of the pass near the head of the Glascarnoch River, between the areas draining eastward and those draining westward

* Mr. W. Morrison, *op. cit.*

† *Annual Report of the Geological Survey* for 1896, p. 18.

into Loch Broom, may probably be attributed to glacial erosion by the ice-streams which have proceeded along it. B. N. P., W. G.

The distribution of the augen gneiss boulders in the western part of the Strath Vaich Forest might, however, be accounted for as the result of a continued easterly carry from much further west, by considering these boulders as the scattered remnants of patches of conglomerate, similar to that of Meall a' Ghrianain, which formerly had a wider development westward than at present. The situation of the Meall a' Ghrianain conglomerate, on the schists at a very high

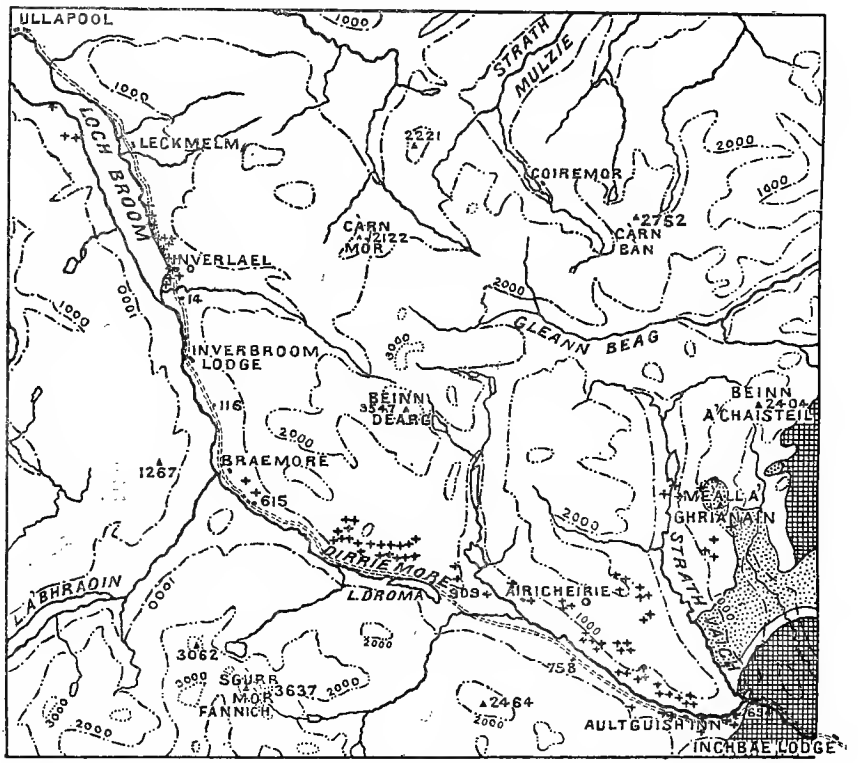

FIG. 14.—Map to show the Distribution of Boulders between Inchbae and Ullapool. Scale: 1 inch = 4 miles. (Airicheirie is called Strathderie in one-inch map.)

level above and more than a mile beyond the western margin of the augen gneiss outcrop, would favour the idea that it formerly extended still further in a westerly direction. The complete absence of augen gneiss boulders west of the granite outcrop, except in these limited areas of the Strath Vaich Forest and along the course of the Dirrie More and the River Broom, the present patchy distribution of these boulders in the Strath Vaich Forest, and their accompaniment by small blocks of Old Red conglomerate, might be due to the fact that they have been derived from areas of Old Red conglomerate which once existed further westward than any now remaining in the district. Any

formerly existing patch of conglomerate near the watershed would of necessity have provided boulders for distribution both to the east and west of the present watershed. C. B. C.

An interesting chapter in the glacial history of Easter Ross-shire is unfolded by the study of the dispersion of blocks of augen gneiss and Old Red Sandstone over the southern and south-western portion of the map, and especially in the area around Ben Wyvis (Fig. 15).

Erratic blocks, carried eastwards from the Inchbae granite and Strath Rannoch Old Red Sandstone areas, are abundant on the lower

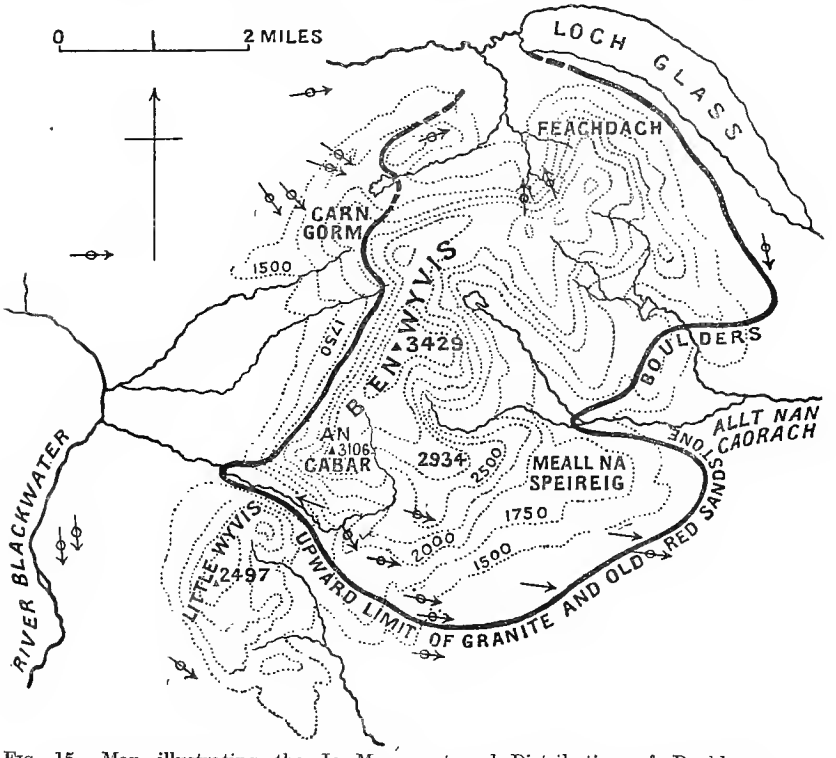

FIG. 15.—Map illustrating the Ice-Movement and Distribution of Boulders on Ben Wyvis. Scale: 2 inches = 1 mile. Plain arrows show direction of ice-movement. Arrows with rings show glacial striæ. (Feachdach = Fiachlach.)

ground to the south and east of the Wyvis range and through the valley of Loch Glass on the north. They also occur plentifully up to a height of 2400 ft. on the top of Carn Gorm and Little Wyvis, the western spurs of Ben Wyvis, but have nowhere been observed above a level of 2300 ft. on that mountain itself. It therefore seems reasonable to suppose that the western ice of the confluent glacier period, by which these boulders were transported, never passed over the summit of the Wyvis range, but was deflected north through the valley of Loch Glass, and south over the hills to the east of Strath Garve, by this great mass of high ground.

The path of the southern ice-stream along the south-eastern

flanks of Wyvis is clearly indicated by the direction of the striæ, the trend of the moraines and the disposition of the erratics.

Crossing over Little Wyvis, it poured through the pass between that hill and An Cabar and swept eastwards round the foot of Meall na Speireig into the valley of Allt nan Caorach. Here it was met by the northern ice-stream which passed through the hollow of Loch Glass, and the two streams, converging, forced a lobe of ice for some distance up the eastern glens of Wyvis, as shown by the augen gneiss boulders found up to a height of 1500 ft. on Allt nan Caorach and its tributary, Allt Coire Misirich.

The absence of boulders of augen gneiss and Old Red Sandstone on the lower north-western slopes of Wyvis and in the bottom of the high pass between An Cabar and Little Wyvis is attributable to the action of the later corrie glaciers; these, pouring out of the high corries to the south of Fiachlach and east of An Cabar, swept away the material left by the earlier ice-sheet.

The level of the confluent ice-sheet on the eastern or lee-side of Wyvis is clearly indicated, on slopes where the later valley glaciation has not swept away the deposits, by a series of shore-moraines, strewn with augen gneiss blocks, and varying in altitude from 1200 to 1600 ft. This is about 800 ft. lower than the conspicuous lateral moraine which extends along the steep western face of the mountain at a mean elevation slightly exceeding 2000 ft., and measures the height to which the impinging wave of the western ice rose on the weather-side of the mountain.

It may be asked why none of these erratics were carried to the summit of Wyvis during the maximum glaciation, on the supposition that the ice-shed may have lain over the gneiss at Inchbae. To this we may reply that there is no evidence that, even at that period, ice from the west passed eastwards over Wyvis, but that this great mass of high ground may have occupied a position on the line of ice-shed, or, at a slightly later period, formed an independent centre of dispersion.

The ice-movement which carried westwards the boulders of augen gneiss found by Mr. Gunn on the shores of Loch Broom, and those already referred to as occurring in this map west of the boundary of the parent rock, was probably initiated within a short distance of the eastern coast of Ross-shire. During the succeeding phase of great confluent glaciers, when the ice-shed lay far to the west, in a position probably not far removed from the present water-parting, boulders of the same rock were carried eastwards and scattered far and wide along the seaboard of Easter Ross. L. W. H.

Next to the augen gneiss the garnetiferous mica schist has provided perhaps the most recognisable boulders. From the band of this schist which crosses from Beinn Tharsuinn, north of Strath Rusdale, to Loch Glass, no boulders appear to have been carried westward, but large boulders referable to this band are found in profusion over the country to the eastward, and are accompanied by others of the garnetiferous amphibolite which is associated with this mica schist.

Carried blocks of Old Red Sandstone conglomerate are not common in the Strath Rusdale and Kildermorie area. One was noticed on the north shore of Loch Glass E.S.E. of Culzie Lodge, and others occur

on the flat hill-top south-east of Loch Magharaidh. Further east, boulders of Old Red Sandstone are not uncommon on the high ground along the parish boundary near Carn nan Con Ruadha and Loch-an Gobhlach. These have probably been carried eastward from the Old Red Sandstone which occurs *in situ* a little to the west. In the Strath Vaich Forest fragments of Old Red Sandstone conglomerate accompany the large augen gneiss boulders on Meall Coire nan Laogh.

No boulders of the Fearn granite were noticed west of the outcrop. Fragments of the pebbly schist in Kildermorie Forest (see Chapter II.) were only observed either on its outcrop, or to the east thereof, and fragments of the Kildermorie hornfels, although extremely plentiful in the drift to the east, were not noticed on the augen gneiss between Loch a' Chaoruinn and Loch na Glasa. Both these rocks, however, rapidly break up into small fragments, and they do not serve, therefore, as good indicators of ice-transport.

Moraines and Morainic Drift.

The moraines on the eastern and western slopes of Ben Wyvis have been already mentioned in describing the distribution of the erratic blocks on that mountain. The drift of the central area is entirely of a loose sandy character, full of fragments of the local rocks, such as siliceous schists, pelitic schists, augen gneiss, amphibolites, hornfels. Types of rock foreign to the district were not observed. This morainic drift is found in the valleys and depressions, and is rarely of any great thickness, but reaches a depth of more than 50 ft. in the hollow between Glen Glass and Boath, and in some places along Allt nan Caorach. Moraines marking the retreat of the valley glaciers are numerous at the foot of Loch Glass and higher up the valley above Wyvis Lodge. They are also found along the Alness River, in the Boath district, at the foot of Loch Morie, along the course of the Abhuinn na Glasa (above Kildermorie) and about Balnacraig and Balalochan in Strath Rusdale. C. B. C.

Moraines laid down at different stages in the history of the later independent glaciers are visible in the valley of the Black Water and most of its tributaries. Fine moraine mounds, both terminal and lateral, are seen in the valley of the Allt Coir' a' Chundrain, to the east of Meall a' Ghrianain. One of the lateral moraines on the east side of the burn is nearly a mile long. Conspicuous terminal moraines on the east side of the same stream, lower down the valley, a mile south of the keeper's house at Strathrannoch, mark different phases in the retreat of the Strath Rannoch glacier. W. G., C. T. C., E. M. A.

Immediately south of Strath Vaich Lodge, a mound, 500 yds. in length and serpentine in form, is the most striking of a group of moraines extending along the west side of the strath. C. B. C.

There is also a fine display of lateral moraines in the deep corries and glens on the head waters of the Allt nan Caorach, on the east side of the Wyvis range.

Boulder Clay.

The boulder clay in the north-eastern part of the map is usually of a reddish colour from the amount of material derived from the

Fearn red granite and from the local Old Red Sandstone strata, It is to be noted, however, that boulder clay is occasionally seen some distance west both of the main area of Old Red Sandstone and of the Fearn granite, and that in these cases the colour is not red but grey or greenish grey. Boulder clay of the latter colour is seen, for instance, in the bank of the Wester Fearn Burn a little above the foot of Abhuinn a' Choire Bhuig. In the stream sections of the Strathrory district the boulder clay is red, from 10 to 20 or 30 ft. in thickness, and very hard and tough in the lower portion, but passes upwards into a looser and more morainic deposit. It is possible that the tough red clay may represent the ground-moraine of the early ice-sheet, the looser material that of the later confluent-glacier period.

C. T. C., L. W. H.

A large part of the pre-glacial valley of the Skiack River is deeply filled with boulder clay, through which the stream at Fannyfield has cut a channel at least 50 ft. in depth without reaching the underlying rock. The section seen in the freestone quarry near Milton of Katewell shows 40 to 50 ft. of grey boulder clay, with included stones of locally derived Old Red sandstone and shale and conglomerate pebbles, with larger boulders of schist and augen gneiss. In the bed of the stream are very large boulders of these rocks and of garnet amphibolite, evidently washed out of the drift.

Mounds of Sand and Gravel.

Sands and gravels of fluvio-glacial origin cover a considerable extent of ground at the foot of the eastern hill-slopes between Novar and the eastern edge of the map. The landward margin of the deposits lies roughly between 200 and 300 ft. above sea-level, while the lower limit merges into the highest raised beach at an elevation of 80 to 90 ft.

Immediately to the north-east of Alness, a wide expanse of gravel extends parallel to the shore of the Cromarty Firth, presenting the undulating uneven surface characteristic of these fluvio-glacial deposits. Near the upper margin, where the gravels rest against the foot of the boulder clay slopes along the 200-feet contour line, they are arranged in a series of steep-sided mounds and confluent winding ridges which enclose circular depressions of the nature of " kettle-holes," and larger hollows filled with peaty alluvium, the site of former lochans. These ridges are shown on the map under the name of the White Hills. They are composed of more or less coarse well rounded or subangular gravel, with nests and lenticular beds of sand and fine shingle. The bedding is very irregular, and conforms generally to the external slope of the mounds.

Conspicuous kamiform ridges of coarse torrential gravels, made up of fragments of Old Red Sandstone and Moine schists, also occur at the foot of Glen Glass, on the slopes above Ballavoulen and behind the village of Evanton. It seems probable that these are marginal deposits, laid down between the hillside and the edge of a shrinking mass of ice that occupied the position of the Cromarty Firth. L. W. H.

Along the southern edge of the wood between Wester Fearn and Upper Ardchronie there runs for about 700 yds. a chain of mounds in a W.N.W. direction, which, from its smooth and regular character and the absence of boulders, seems to partake more of the nature of a kame than a true moraine. Near the fork in the streams about three-

TERRACES OF GLEN GLASS, WITH MORAINE OF RETREAT IN BACKGROUND.

quarters of a mile W.S.W. of the Ordnance Station 864 on Blar Garvary, there is a beautiful set of sand and gravel mounds of the esker type, with well rounded pebbles. These mounds are at a height of nearly 900 ft. above the sea, and are sometimes sharply curved. A similar mound on the south side of Abhuinn a' Choire Bhuig, just above the foot, shows about 40 ft. of sand and gravel, mixed with boulders in the lower part: no clear bedding is observed. A serpentine mound, probably of the same character, may be seen at a height of more than 500 ft. above sea-level on the hillside about one mile to the east of Easter Fearn. W. G., C. T. C.

Terraces of Glen Glass and Allt nan Caorach.

A remarkable series of terraces fills the valley of the Glass between Eileanach and Redburn, and forms a striking feature in the landscape seen from the lower part of the valley (Plate VIII.).

These terraces are flat-topped and appear horizontal to the eye, but are found by the Abney level to have a general gentle slope down the valley, and at one point, half a mile above Redburn, an inclination of 1° in the opposite direction. At Tighnacreige, where they attain a maximum breadth of rather more than half a mile, at least five of these successive benches can be detected, the level of the highest being about 760 ft., or 47 ft. above the present level of Loch Glass. They decrease in number down the valley, and for some distance above Redburn, on the northern side, one high terrace only rises with a steep front above the alluvial haughs of the River Glass, which has cut a wide and deep channel through these earlier deposits. Sections of the terrace above Redburn show it to be composed of coarse torrential gravel alternating with lenticular and inconstant beds of fine current-bedded sand. The stones in the coarse shingle usually lie with their higher ends pointing up the valley, indicating that they were laid down by water coming from that direction.

A similar terraced arrangement of the deposits can be traced for some distance up the Allt nan Caorach, where five terraces can be made out in places on both sides of the river. They are, however, fragmentary, and often completely removed by denudation.

It seems probable that these fluvio-glacial sands and gravels were laid down, partly by the eastern drainage of Wyvis and partly by melt-water from the retreating ice, at a time when the two streams of ice which swept round the Wyvis *massif* had ceased to meet. The valley below Redburn was blocked by the southern ice-stream, while the extremity of the northern glacier, retreating up the hollow of Loch Glass, lay somewhere about the position of Eileanach. The conspicuous hummocky ridge which crosses the valley at the falls below Eileanach is probably the terminal moraine of this glacier, laid down during a pause in its retreat.

The successive terraces on either side of the valley represent further pauses at different levels of the shrinking glaciers, and the deep glen through which the Allt a' Ghlinne * flows at the foot of the boulder clay slope beyond the terraced gravels, marks the position of the overflow channel of the waters ponded back between these two masses

* The stream that flows just north-east of the terraced area, between Tighnaereige and Redburn.

of ice. The channel has been deepened and modified, especially towards its lower part, by subsequent erosion by the present stream; and its continuation further down the valley is indicated by a faintly marked line of feature and alluvial deposits on the hill-slope east of Redburn.

Terraces between Allt Dearg and Strathrory River.

Fine examples of lateral terraces and marginal stream-channels are seen between the Allt Dearg and the Strathrory River, six miles north of Alness. They cover the ground between the Aultnamain road and the edge of the map, and extend for a short distance into the adjoining Sheet (94).

The sections cut by the small streams that cross the road near the 782-ft. bench-mark, in the deep drift that covers the slopes of Druim na Gaoithe, show 20 to 50 ft. of drift, the lower part tough reddish boulder clay, the upper loose and morainic in character capped with 4 to 6 ft. of fine and coarse tumultuously arranged gravel containing large blocks of Fearn granite, Moine schist, augen gneiss and Old Red conglomerate. This gravel capping forms a succession of terraced features sloping gently down the valley. Along the upper side of each runs a sinuous hollow, marshy or peat-filled, cut deeply through the drift. Many of these channels are dry; others are occupied by small streams, and have been considerably deepened and modified by subsequent stream erosion. They evidently represent lines of marginal drainage at successive levels along the edge of a shrinking glacier which occupied the present valley of the Allt Dearg. The marshy flat, known as Luachar Mhor, which lies just outside the limit of this map, marks the site of a lake which occupied the hollow left by the melting ice at the last stage in the history of the glacier. This lake was held in by the terminal moraine which crosses the mouth of the Allt Dearg valley a third of a mile north-east of Strathrory, and has now been cut through by the stream.

L. W. H.

NORTH-WESTERN AND NORTHERN AREA.

In this area the level of the ground is generally higher than in the area already described, though none of its mountains is so high as Ben Wyvis. That the carry was never westward in the northern and north-western area is indicated by the absence in this area of augen gneiss boulders west of the crops of that rock, except in a few localities where such boulders may have been carried during a local late glaciation down slopes inclining westward, or where they may have been carried from the south-west in a direction striking more nearly north than the adjacent margin of the gneiss. As already stated, boulders of augen gneiss, possibly derived from the Old Red conglomerate of Meall a' Ghrianain, are tolerably common near the lower part of the burn flowing eastward by Lubachlaggan, but not further north. Various bands of schist strike across the area in a north or north-east direction, but these have provided no boulders for general distribution to the west. For instance, no boulders of the broad zone of coarse pebbly schist, which extends over Beinn a' Chaisteil and Carn Crom-loch to Dunan Liath, have been found on

its west side, though such boulders are common on the east. Boulders of augen gneiss, which are occasionally found, as already intimated, west and north-west of the nearest crop of this gneiss, are seen near the head of Abhuinn Coir' a' Mhalagain and along the glen north-east of Cnoc nan Sac, but those which appear to have been transported glacially are rare in comparison with the others, which, since the glaciers passed away, have been carried north-westward along stream courses, such as the Water of Glencalvie and the burn east of Cnoc nan Sac.

A number of glacial striæ have been found, chiefly on quartz veins, on the high ground between Glenbeg house and the head of Coire Mor. These strike S.S.W. and N.N.E., and are believed to indicate an ice-movement in the latter direction. Along the slopes and in the bottom of Gleann Beag the glacial phenomena indicate a movement eastwards down the glen, many boulders of the pelitic gneiss at the head of the glen being found some miles further down.

The striations on the high ground of Carn Crom-loch, Leac Ghorm, Dunach Liath and Cnoc nan Sac, all of which lie north-west of the augen gneiss, strike east or north-east, or in intermediate directions. A number of striations have been preserved on the granitic rocks near Carn Dubh, Carn Salochaidh and Carn an Liath-bhaid, and most of these strike E.N.E. or north-east. On the higher parts of Carn Chuinneag only a few boulders were noticed which could not have been derived from rocks *in situ* on the hill: one of siliceous schist occurs at a height of about 2550 ft., and there are also others of diorite at a height exceeding 2500 ft. Similar dioritic rocks form considerable areas further west near the head of Glen Diebidale, but do not occur to the east, and so there can be little doubt that both they and the boulders of siliceous schist have been carried from the west.

Most of the drift is of a loose morainic character, and prominent morainic mounds and ridges are common. A group of terminal moraines with rude semicircular forms is seen near the foot of Toll Lochan, and is doubtless due to a glacier descending from the corrie south of the loch. On the north side of Gleann Beag, about a mile below Glenbeg house, a series of morainic banks strikes north-west, and seems to represent portions of the terminal moraines of a glacier coming down the glen. On the north side of the valley east of Bodach Beag a morainic bank is traceable in an almost straight E.N.E. direction for about a mile, the level gradually decreasing eastwards. It is probably a lateral moraine of the northern side of the glacier which once filled the valley.

In a few places under the loosely compacted morainic drift we find a stiffer, harder bouldery deposit which may be classed as boulder clay. A deposit of this kind, of a brown colour, is well seen by the roadside a third of a mile below the foot of Lochan a' Chairn.

Plateau Frost Debris.—The gentler slopes and flat tops at great elevations are very often covered, not with morainic drift, but with a smooth-surfaced material consisting of small flat slabs and subangular fragments, which is derived from the disintegration of the rock occurring *in situ* underneath. This material is by no means confined to the north-western and northern area, but is generally more

widespread therein than in the rest of the map. It is often noticeable that this disintegrated rock changes its character sharply along lines running just above the boundaries of the rocks from which it has been derived. But on the lower slopes it attains a considerable thickness, and may have glided or slipped down, and is difficult to separate accurately from drift which may be far transported. On some nearly level hill-tops, among which we may specially mention Carn Ban, Meallan Ban and Beinn a' Chaisteil (Frontispiece), we can walk two miles in a nearly straight line without seeing near our course any rock save this very porous disintegrated material, or the extensive sheets of moss which locally cover it. Even on gentle slopes, however, the material is subject to earth-creep (perhaps from the abundant water which accumulates in the lower layers), and is rearranged in narrow subparallel terraces, separated from one another by small nearly vertical scarps, often from one to three feet in height. These little terraces are very well seen on the N.N.E. side of Meall a' Ghrianain, on Meall Gorm and the west side of Carn Ban.

Such coverings of disintegrated rock have not been noticed at low levels, perhaps nowhere below the 1000-foot contour. It may well be that the variations of temperature at the higher levels, being greater than at lower, would always tend to produce a greater mechanical disintegration at high levels than at low, but it is also suggested that the main sheets of disintegrated rock may have been formed while much of the lower ground was still occupied by ice, at a time when the cold was still very intense and had greater power than now to break up rock exposures.

Lochs are not now abundant in the area, but were evidently more so formerly, a considerable number having been filled up by alluvium and peat since glacial times. Among these old filled-up lochans we may mention instances in the following localities :—

Gleann Beag, at and just above Deanich Lodge. Half a mile south-east of Carn na Speireig. Rather more than half a mile east of Loch na Gabhalach Nodha. Nearly half a mile E.N.E. of Cnoc nan Sac. Half a mile W.S.W. of Creag Illie. Half a mile north-east of Lochan a' Chairn.

Loch Coire Mhic-mhathoin, on the north side of Gleann Beag, and the nameless loch half a mile E.N.E. thereof, may be cited as examples of rock basins. The alluvial patch lying almost between these two lochs also, no doubt, represents a former rock basin which has now been filled up. Toll Lochan, Gorm Loch, Crom Loch and Lochan Sgeireich are, on the other hand, dammed up by morainic drift.

C. T. C., C. B. C.

Alluvia and Recent Deposits.

marine alluvia.

Cromarty Firth.

The highest of the ancient sea margins—"the 100-foot beach"—forms a distinct feature along the eastern shore of the Cromarty Firth. Its upper limit, which is nowhere more than 350 yds. from present highwater mark, is between 80 and 90 ft. above sea-level.

The margin of this beach is also fairly well defined on the opposite side of the Firth, though the surface is often considerably denuded. The beach extends inland for rather more than half a mile at Alness, where the height of the margin is 85 ft.

Fragments of the denuded 50-foot beach are found between Alness and Evanton and near the Church at Balconie, and a lower beach with an elevation of about 25 ft. extends for some distance westwards from Teaninich House. The old coast-line of a later period can be seen immediately above the present beach near Mountgerald, on the southern margin of the map. A low sea-cliff of sandstone and conglomerate rises above the shore road, and a scar on the shore at the old chapel gives a section of 12 ft. of sand and gravel resting upon dark sandy clay filled with remains of recent estuarine and littoral shells, and trunks of trees. A wide stretch of stony sand, known as the Ardroy Sand, is exposed above lowwater mark in Alness Bay, between the projecting deltas of the Alness and Glass Rivers. A feature of the Cromarty Firth is the number of large ice-borne boulders of igneous and metamorphic rocks that strew the foreshores between tide-marks.

L. W. H.

Dornoch Firth.

Traces of a raised beach, at an elevation of between 40 and 50 ft., are found along the south side of the Dornoch Firth (at the north-east corner of the map), and near Kincardine the railway passes through a deep cutting in these deposits.

The hollow to the north of the promontory of Creich, on the Sutherland shore of the Kyle, is to a large extent occupied by the deposits of the partially denuded 100-foot beach. The highest point in the centre of the hollow is 84 ft. above sea-level, and it is evident that this promontory was once an island. A large mud flat has been deposited in the eddy behind Dun Creich, caused by the constriction of the waters of the Kyle opposite the deltas of the two Fearn Burns, and has probably originated from the denudation of a grey clay which is found along the shore of the adjoining bay, and seems to extend inland beneath the beach deposits. W. G.

FRESHWATER ALLUVIA.

There are no extensive deposits of freshwater alluvium within the limits of this map. One of the largest is found between Gorstan and Garve, and represents the upper part of Loch Garve (one-inch map 83), which has been filled up by the detritus brought down by the Black Water.

The alluvial flats of the Glascarnoch valley are, near Strathderie, more than half a mile broad. These and the smaller flats in Strath Skiack and in a wide part of Gleann Beag, near Deanich Lodge, probably indicate the positions of old lake basins which are now entirely filled up. A considerable alluvial plain occurs at the head of Loch Luichart, and has been principally formed of sediment brought down from the west by the River Grudie : the other river that joins the River Grudie at Grudie comes from Loch Coulin (one-inch map 83) almost free from sediment.

Narrow strips of alluvial sand and gravel occur along the sides of

most of the principal streams, and are well developed in Strath Vaich, Strath Rannoch, Strath Rusdale and Glen Calvie. At the foot of the latter glen four terraces can be distinguished, at heights of about 5, 15, 22 and 32 ft. above the normal level of the burn, and a little above the highest of these there is also an obscure shelf of erosion which may probably be referred to older river action. Higher up the same glen, at the foot of Abhuinn Coir' a' Mhalagain, four terraces can again be distinguished, the two highest of which reach about 40 and 45 ft. above the usual water level.

On the east side of the valley half a mile north-west of Cnoc nan Sac, several terraces can be traced some distance from the side of the burn in a north-easterly direction. Possibly they have been formed at a time when the burn drained north-easterly down the valley which reaches the margin of the map to the north of Carn Salochaidh. Perhaps the burn was for a time compelled to run in this direction by ice, coming down the valley of the Carron and Glen Calvie, which blocked the natural straight drainage into the Carron. The highest of the terraces referred to can be traced about 700 yds., and is about 85 ft. above the normal level of the present burn.

At the foot of many of the steep mountain torrents, in Gleann Beag, Gleann Mor and elsewhere, steep cone-shaped deltas have been deposited. Deltas of considerable size are being laid down in the Cromarty Firth, at Alness and Evanton by the Alness, Glass and Skiack Rivers: and a constriction of the Kyle of Sutherland opposite Creich is being caused in a similar manner by the alluvial deposits of the Easter and Wester Fearn Burns. B. N. P., C. T. C.

Peat.

A large extent of ground in the central and south-western portions of the Sheet is covered with hill-peat. This is particularly the case in the area of comparatively low ground occupied by the augen gneiss between Strath Rannoch and the head of Strath Rusdale. The average depth of the peat over most of this area is about 6 ft., but it occasionally reaches a much greater thickness. C. B. C.

The lower slopes on the western and south-eastern side of the Wyvis range are largely peat-covered, and the valleys drained by the head waters of the Allt nan Caorach contain extensive peat mosses. The depth of the peat in the mosses round Loch Misirich varies from 4 to 8 ft. Throughout the area, and especially on the higher slopes, the peat is wasting, leaving bare the large stools of *Pinus sylvestris*, which occur at various levels in and sometimes at the base of the deposit. The remains of birch trees are also found in many of the mosses, and, where seen, they are always at or near the base of the peat. L. W. H.

In several places on the high plateaux in the north-western portion of the map the peat mosses reach a height exceeding 2500 ft., and a moss on the east side of Meallan Ban touches the 2750-foot contour. The northerly continuation of the last mentioned moss is bare of any cover of living moss over a considerable area, and presents a striking appearance of wasting denudation. Stools of the Scots Fir (*Pinus sylvestris*) are usually abundant in the peat in the north-western district up to heights of 2000 ft.

A considerable number of old lochans are still distinctly represented by flat-topped peat mosses with somewhat ill defined sides, the neighbouring slopes being also to a large extent covered with peat. As instances, we may mention the moss half a mile W.S.W. of Creag Illie (head of Glen Diebidale), and another example three-quarters of a mile south-west of Glenbeg house.

The peat on some alluvial flats was not mapped,* for fear of obscuring the history of the development of the valley.

In a district widely covered with peat, it is noteworthy that a considerable part of the drainage is carried on by small streams which frequently run in tunnels, the sides and tops of which are formed of peat. The tops of these tunnels are liable to fall in, and the stream is then exposed to daylight for a certain space. Good examples of these broken tunnels are to be seen a little above the head of the stream which drains north-east into Coire Bog.

In addition to the peat which represents old lochans or which has grown on alluvial terraces, a considerable proportion of peat lies on rather flat slopes, where the drainage must have been slow even before the peat began to grow. In some places, however, it covers somewhat steep slopes and is liable to slip violently downhill. On the hillside about 1100 yds. slightly east of north of Deanich Lodge, a well laminated peat, with some layers partly composed of birch, has evidently slipped from the position of growth, and the laminæ have been considerably contorted and broken.

Part of the small moss on the flattish area about three-quarters of a mile north-west of Cnoc nan Sac is formed of plant remains, which Mr. Clement Reid has kindly examined. He states they represent stems and rhizomes of the common reed (*Phragmites*) with twigs of heath (*Calluna*). The reeds must have grown either in a loch or a swamp, though the present position is tolerably dry and not suggestive of either.

An unusually extensive peat moss covers the comparatively low and flattish area in the upper part of the Coire Bog, four or five miles south-west of Kincardine. This has been carefully examined by Mr. F. J. Lewis.† As a result of his examination, he states that the earliest vegetation that took possession of the land on the passing away of the glaciers consisted of Arctic willows : these were quickly followed by a close growth of other creeping willows mixed with a good deal of *Potentilla comarum*, Nestl., and some *Empetrum nigrum*, L., and *Arctostaphylos alpina*, Spreng. The dominance of *Dryas octopetala*, *Salix reticulata*, etc., in the basal layers indicates severe Arctic conditions. Above the Arctic beds the vegetation gradually underwent a change—the *Salix*, hitherto so dominant, disappeared, and the ground became entirely covered with *Empetrum* mixed with *Eriophorum* — *Arctostaphylos alpina*, Spreng., still lingering on sparingly. After some 18 in. of peat, formed almost entirely of *Empetrum*, had been deposited, the *Empetrum* died away, and a growth of *Betula alba* of small size—most of the stems being less than 8 in. in diameter—covered the district, and persisted until 2 or 3 ft. of *Betula* remains had accumulated. After this, the moss became tenanted with a wet moorland vegetation consisting chiefly of

* This was before the peat was shown on the maps by overprinting.

† 'The Plant Remains in the Scottish Peat Mosses,' *Trans. Roy. Soc. Edin.*, 1908, vol. xlv. p. 335.

Eriophorum mixed with a good deal of *Calluna* (heath). This persisted until 2 ft. of additional peat had been deposited, and then came in a great growth of almost pure *Calluna*, representing much drier conditions than before. This *Calluna* peat became then quickly covered with *Pinus sylvestris* (Scots Fir), which attained a large size. In many places two distinct zones of *Pinus sylvestris* are indicated, separated by 1 or 2 ft. of *Sphagnum* peat. A considerable period seems to have elapsed between the passing away of the upper band of *Pinus sylvestris* and the incoming of the present type of vegetation, for quite 2 ft. of *Scirpus—Sphagnum—Eriophorum* peat lies upon the top pine zone, and indicates a considerable duration of wetter and colder conditions than those which prevailed while the pine was growing.

It is noteworthy that in the basal portion of the same peat moss fragments of beetles' wings are very abundant in certain layers, but in too poor condition to admit of determination.*

In other localities a little west of the Coire Bog, for instance by the burn nearly a mile below the outlet of Lochan a' Chairn, it has also been noticed that remains of *Betula nana* are abundant in the lower layers of the peat, while *Pinus sylvestris* is common in the higher layers.

Mr. Lewis estimated the average depth of the peat in the Coire Bog at 12 ft., but in some places it is probable that the thickness is considerably more than this. The nearly flat smooth-surfaced moss which is called Blar Garvary, about a mile east of the Coire Bog moss, is reputed locally to be 40 ft. deep, but we do not know on what grounds this belief rests. C. T. C., C. B. C.

Landslips.

A considerable number of landslips have been noticed, chiefly in the north-western part of the map, but none are large. Perhaps the largest example is that on the east side of Bodach Beag, but this is less than half a mile in length, though there are two minor slips very near on the south side. In these three cases the direction in which the slip has taken place is much the same as that of the dip of the foliation. A similar relation is also seen in slips on the north side of the valley about three-quarters of a mile below Deanich Lodge, and on the north-east side of Meall a' Ghrianain.

Part of the slipped masses three-quarters of a mile below Deanich Lodge appear to have slipped again at a comparatively recent period, subsequent to the formation of a gravel terrace, the top of which is about 10 ft. above the usual level of the adjacent burn.

The eastern boundary of a slip on the south face of Cail Mhor, Gleann Beag, is very straight, and coincides, at all events in part, with the outcrop of a fault, a continuation of one of the Coire Mor faults (see Chapter IX.), which inclines westward towards the centre of the slip.

A slipped mass of granite, at the bottom of the slip in the foliated granite on the south side of Glen Diebidale, has the form of a needle, and forms a striking feature in the landscape. The direction of the dip of foliation is in this case, not down the hill-slope, but towards rising ground.

* *Summary of Progress of the Geological Survey* for 1903, p. 87.

WEATHERING.

A soft decayed condition, without the accompaniment of any marked mechanical breaking up, is found in the schists in the burn half a mile east of Carn Ban, and in various other localities mentioned in Chapter II. There is no reason to suppose that these localities were less exposed to glacial scour than the adjoining tracts, and it is difficult to see how any soft superficial material existing in these localities prior to the advent of the ice could have escaped subsequent erosion. It seems probable, therefore, that the decayed condition has been brought in after the localities referred to became free from ice, or at all events from moving ice.

A considerable part of the surface of the Fearn granite is in an equally soft decayed condition down to considerable depths. In this case the outcrop of the granite bears an unusual number of scattered erratic blocks, and there is good reason to suppose that a considerable part of it was for long in the path of a great mass of ice moving from the south-west.

Considerable areas of material, in which there has been much mechanical breaking up of rocks *in situ*, presumably by frost action, have been described in an earlier part of this chapter. C. T. C.

CHAPTER XI.

ECONOMICS.

AREAS OF DEER FOREST AND FARM LAND.

THE areas of cultivation and the populated regions are practically confined to the Old Red Sandstone country on the east side of the map. With the exception of a narrow strip of cultivated ground along the shores of the Kyle at Creich and Kincardine, and some scattered crofts in the lower part of Strath Rusdale, almost the whole of the region west of the Old Red Sandstone belt is given up to deer forest and grouse moor, and the population limited to a few shooting lodges and keepers' houses in the glens.

The sandy boulder clay, derived from the waste of the Old Red Sandstone, that covers the seaward slopes of the Cnoc Fyrish range, the northern side of the Alness River valley and the Black Isle, affords a fertile loamy soil which yields excellent crops of roots and cereals on the lower ground along both sides of the Cromarty Firth.

A little below the 200-foot contour-line, where the boulder clay is succeeded by fluvio-glacial deposits and the sands and gravels of the highest raised beach, the soil becomes very light and stony, but at a lower level it is again of a more loamy nature, owing to the admixture of the estuarine clays which underlie the sand and gravels of the higher beaches.

TIMBER.

The soil that covers the well drained hill-slopes which face the Firth of Cromarty is eminently adapted for the growth of coniferous trees, and the plantations on the Novar Estate, which form a continuous stretch of woodland between the Glass and Alness Rivers, are noted both for the fine quality of the timber produced and for the scientific methods employed in their management.

* The fir woods rise to a height of 1172 ft. on Cnoc Duchaire, and to 1460 on Cnoc Fyrish; but owing mainly to the effects of the wind, the trees, especially the Scots pine, become stunted at altitudes above 700 or 800 ft. in exposed situations, and above 1000 ft. in more sheltered localities. The older coniferous woods are 868 acres in extent, and consist chiefly of Scots pine with an admixture of larch and spruce and a few hardwood trees. The hardwoods cover 56 acres on the lower ground, a considerable proportion of the trees being oak, in addition to beech, lime, ash and elm. The younger plantations occupy 1813 acres, in which the principal tree is Scots pine, intermingled with a varying proportion of larch, spruce and silver fir. Extensive fir woods also clothe the hill-slopes on the north side of the

* From information kindly supplied by Mr. J. Meiklejohn, Novar.

Alness River valley above Ardross, Stittenham and Achnacloich ; and smaller plantations occur in Strath Skiack, on Tulloch Hill and at Strathgarve. L. W. H.

There are 4424 acres of woods on the Ardross estate, some 3143 acres of which were planted between 1848 and 1855, so that the trees now (1907) chiefly range between fifty-two and fifty-nine years of age. The trees on 125 acres are seventy years old, and 212 acres have been planted within the last twenty years. Of the whole acreage about 1400 acres are on Moine schists, the remainder being on the Old Red Sandstone and nearer the sea.

In a report of a recent survey of the woods for Mr. Perrins, the proprietor, by Professor Schlich, in the total area of 4088 acres, which excludes the policy grounds, 1696 acres are classed as quality 1, best productive, 1422 as middling quality 2, and 701 as lowest.* Of the 1400 acres planted on the Moine Schist area, 713 acres are reported as of quality 1, best productive, so it appears that this area is well adapted to the growth of trees as far as the soil conditions are concerned. In this connection it may be pointed out that the drift-carry in this area has been from the westward, and that the superficial deposits overlying the Moine schists consist of glacially transported fragments of these schists and of granite. The woods run up the hillsides to an elevation of about 1200 ft. above sea-level, but profitable forestry may be said to cease at an elevation of 1000 ft., owing to high altitude and strong winds combined. The most dangerous wind comes from the north-west. The principal trees are Scots pine and larch, and next to these spruce. There are also in the policy grounds which flank the river some oaks, Douglas fir and other species. C. B. C.

Natural birch wood grows freely along the lower parts of the principal glens and valleys, especially in Gleann Mor, Strath Vaich, and the lower part of the Black Water ; and also fringes the shores of Loch Morie, Loch Glass and Loch Luichart. A few gnarled and ancient Scots pines, the remnants of the vanished Caledonian Forest, still survive in Alladale, Strath Vaich, and near the head of the valley of Abhuinn Coir' a' Mhalagain. In the latter locality these trees are evidently all in a dying or dead condition. Most of them are below the 1000-foot contour and on morainic mounds ground composed of rather loose soil. The situation is sheltered from the west wind, and the glen has been under deer for some years, so that the want of young Scots pines cannot be attributed to the nibbling of sheep.

C. T. C.

PEAT.

Peat is still used locally for fuel in various parts of the district by the crofting population. In some places the cutting of it is much impeded by the numerous embedded stools of Scots firs, but, on the other hand, these stools may themselves be used for fuel after they are cut up and dried.

The most extensive deposits are those on the comparatively low ground in the Coire Bog and in the area between the head of Strath Rusdale and Strath Rannoch. In the latter area the average depth is

* Mr. Cuthbert, Mr. Perrins' factor, has kindly given a copy of this report, which has been freely used in writing this account.

estimated at 6 ft. In the former, Mr. F. J. Lewis supposes the average depth to be 8 to 12 ft.* In some places the depth is no doubt considerably more than the above estimates. The large flat peat moss two or three miles south-west of Kincardine is locally reputed to be 40 ft. deep. W. G., C. T. C.

IRON ORES.

It was known long ago that hæmatite iron ore occurred in or near the Old Red Sandstone in the eastern part of the area. In "The New Statistical Account of Scotland,"† it is stated that "about five miles from the Firth (of Cromarty), and on the property of Finlay Munro of Lealdie,‡ an iron ore has been discovered which, from all appearance, may be of considerable extent. Previous to the writing of the former Statistical Account, a specimen was sent to the Carron Company at their own desire, which was found to yield 75 lb. iron per cwt.§ The rock in which the vein occurs is a gneiss, and it is worthy of remark . . . that the metallic iron is injected into the primary rock at a point not many yards distant from its junction with the aqueous or sedimentary strata." It would naturally be supposed that in the above passage the "gneiss" must be some rock of the Moine Series, but our inquiries have made it probable that the locality referred to is about half a mile from the Moine schists, and in the Old Red Sandstone conglomerate rather less than half a mile west by south of Ardross Castle. Here hæmatite iron ore is now visible along the course of the Loch Morie fault in the south bank of the River Alness, where the ore occurs in branching veins and along joint faces, and fills up the interstices of the shattered conglomerate along the fault.

Perhaps in reference to the same locality Mr. William Morrison states || that "in Strath Rusdale is found so large a quantity of good hæmatite that a Birmingham firm offered Ardross £2000 a year for the mining of one huge rock." It is also stated by Mr. John H. Dixon ¶ that "at the iron smelting works near Alness a native hæmatite iron ore was used, as well as what is termed bog iron."

In the neighbourhood of Blackpark, in the parish of Edderton, and situated on the extreme north-eastern margin of the map, there are small deposits of bog-iron ore. The ore appears to have been smelted in past times in the primitive "bloomeries," traces of which are still to be seen at Blackpark, on the Allt Muigh-bhlaraidh, and in another locality a quarter of a mile east of Aultnamain Inn. Mr. W. Ivison Macadam states that at the old iron works in the first mentioned locality both bog-iron ore and hæmatite were used, and that at the side of the works there is a vein of hæmatite.**

Pieces of iron slag are abundant on the north side of the Garbh Allt, about 360 yds. west of Salachie. L. W. H.

* 'The Plant Remains in the Scottish Peat Mosses,' *Trans. Roy. Soc. Edin.*, 1908, vol. xlv. p. 343.

† Vol. xiv. pp. 136, 137 : 1845.

‡ Presumably 'Lealty' of the Ordnance maps.

§ Pure hæmatite yields 78·4 lb.

|| Notes printed in Report of the Boulder Committee of the Royal Society of Edinburgh, *Proc. Roy. Soc. Edin.*, 1880–1881, vol. xi. v. 759.

¶ 'Gairloch, in North-West Ross-shire,' p. 73, Edinburgh, 1886.

** 'Notes on the Ancient Iron Industry of Scotland,' *Trans. Inverness Scientific Soc.*, vol. iii. p. 222. Read in 1887.

TINSTONE.

The peculiar bands of garnetiferous albite gneiss of Diebidale, in which are found black strings composed chiefly of magnetite, but with some tinstone (cassiterite), have been already described (Chapter IV.). It seems not impossible that in the future they may prove of some economic value, but, as they are situated in a deer forest, no exploring work to test them practically has yet been undertaken. Some details regarding their thickness, strike, etc., have been given, and their relations are further shown in the annexed map (Fig. 16), but it is important to remember that a considerable area of ground near the exposures is covered with slipped material and drift, and that there is evidence that magnetite-cassiterite rocks occur also under this superficial cover.

Only two bands are exposed that seem of any importance, and the width of the largest is not more than 15 yds. Outside these, and one or two much narrower bands, magnetite is disseminated in small patches and crystals through the adjoining granitic rocks, but no specimens of these adjoining rocks have yet been found by microscopic examination to contain any cassiterite. It is therefore to be feared that the cassiterite is confined to the black strings.

These black strings always contain a much greater proportion of magnetite than cassiterite. In various samples tested by Dr. Pollard the proportion of cassiterite was found to vary from 0 to 15 or 17 per cent. The thin sections examined under the microscope by Dr. Flett also show in some cases very little cassiterite, and in others a good quantity. The cassiterite is not disseminated evenly through the iron oxide, but occurs in irregularly distributed patches or nodules composed of small brown crystals, most of which are nearly equidimensional, but a few are elongated rod-like prisms.

The black strings containing the cassiterite only form a small proportion of the gneiss bands in which they occur. The proportion has not been estimated carefully, but is thought perhaps to be about 5 per cent. Occasional strings may be as much as three or four inches thick, but most of them are less than an inch.

The following is the analysis, executed by Dr. Pollard, of black ore material obtained from chips detached from three different parts of one hand specimen, but it cannot be regarded as an indication of the mean composition even of this specimen :

SiO_2	7·97
Al_2O_3	0·98
Fe_2O_3	60·69
FeO	25·94
MnO	0·16
CaO	0·59
MgO	0·26
SnO_2	3·22
H_2O at 105° C.	0·06
H_2O above 105° C.	0·43
Total	100·30

Alkalies not estimated. No other elements except a trace of titanium and a doubtful trace of tungsten were found.

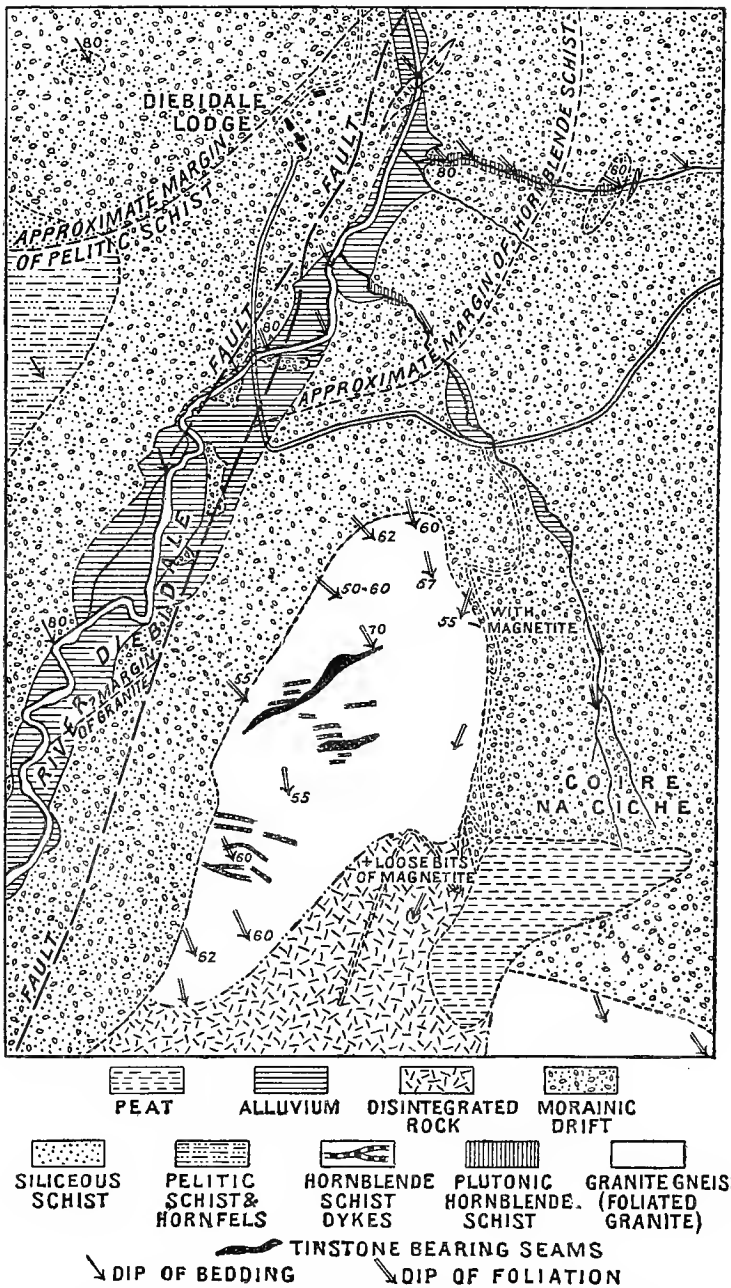

FIG. 16.—Map showing Tinstone-bearing Bands in Glen Diebidale. (Diebidale Lodge is in ruins.) Scale: 6 in. = 1 mile.

Sir W. Ramsay was good enough to examine two of the specimens for radium, and reported that they show no radio-activity whatever.

If, in the future, attempts should be made to further explore the neighbourhood, it would perhaps be advisable in the first place to take steps to bare the rock more completely, both in the craggy ground and the adjacent drift-covered area. For this purpose it might be well to resort to the system of "hushing," which has long been in use in the mining districts of the North of England. In this method water is collected in a reservoir above the level of the ground to be bared, and is then released in a sudden flood along a preliminary cut in any desired direction. The cut is thus greatly deepened and widened into a "hush," at the bottom of which the clean rock is exposed. Water for hushing purposes might perhaps be carried from Loch Chuinneag in open conduit, which could collect various small streams and springs *en route*.

Water could readily be got at a lower level, both to provide power for crushing purposes, and for washing, from Diebidale River itself. This river flows 300 or 400 yds. west of the outcrops which contain the magnetite-cassiterite strings.

GALENA.

In a burn running eastwards on the west side of Glen Calvie an intrusive igneous rock striking E.N.E., perhaps a lamprophyre, is seen in several places in a greatly crushed condition, along with veins of ferriferous carbonate and quartz. The veins contain occasional specks of iron pyrites and galena, and the width of crushed and veined rock is in places as much as 8 or 9 ft., but no large pieces of galena were detected. C. T. C.

ROAD METAL.

In the Easter Ross district the roads are metalled with stones out of the drift, picked off the fields along the line of the road and from the shore. The roads in the interior are repaired with gravelly morainic material from pits at the roadside.*

The latter material is not good for use where the traffic is heavy. If it is desired to obtain some better local stone, attention should perhaps be directed to the less sheared portions of the pelitic hornfels, such as that near Kildermorie (described in Chapter V.) and that in the crag on the east side of Strath Rusdale close to the road S.S.W. of Meall Bhenneit. Messrs. Lovegrove, Flett and Howe state that in their experiments on stones for road metal use they found the hornfelses to occupy a position above the average of the stones tested.† They suppose that the heating the hornfelses have undergone has driven out part of their water of composition, and has recrystallised many of their minerals: and that hence the grains are usually fresh and comparatively hard. It is important to remember, however, that those hornfelses which have been sheared must have lost their original qualities in proportion to the shearing undergone.

The Older (foliated) Granites are generally in such a granulitic condition that they probably would not stand much wear and tear.

* From information supplied by Mr. A. Joass, Surveyor of Roads, Dingwall.

† 'Road-Making Stones. Attrition Tests in the Light of Petrology,' p. 60, London, 1907.

The Newer Granite of Fearn is usually decomposed and in a soft condition for a considerable depth below the surface. L. W. H., C. B. C.

BUILDING STONE.

There are small freestone quarries in the Old Red Sandstone at Foulis; on the shore at Drummond, near Evanton; and at Alness. The stone, which is somewhat soft and perishable, is used locally for building purposes. L. W. H.

On the southern side of the Dornoch Firth there is, within the Sheet being described, only one small quarry, nearly half a mile south-east of Kincardine Church. The quarry is in one of the small bosses of Newer Granite. The rock appears to be of good quality, but the outcrop is not large. Most of this Newer (Fearn) Granite is in a soft decomposed condition near the surface, as already stated. It is a fine or medium-grained reddish biotite granite, not unlike the Cairngorm granite. On the Sutherland or northern side of the Firth there is a fairly large old quarry east of the village, and near the road, where the ordinary siliceous schist of the district was got out. This rock seems generally to be used for walls and buildings all over the district, but has in most cases been obtained from the numerous scattered boulders. It is extremely durable, no doubt, but hard to quarry and to shape, and therefore the stone used for doors and windows is often obtained from the Old Red Sandstone areas. W. G.

The Older (foliated) Granite has been considerably used for building purposes, but the quantity needed has been supplied by boulders, which are often found of very large size. It is said that one of the boulders which was broken up in Strath Rusdale for building purposes provided more than enough stone for two cottages. It is to be noticed that these boulders are more widespread than the rock *in situ*, for in glacial times they have been carried far eastward of the outcrop and to some extent westward also (Chapter X.). The granulitic character of most of the felspar and quartz makes the rock easier to work than it otherwise would be.

The varieties of the Older Granite, such as the augen gneiss of Inchbae, which possess conspicuous felspar phenocrysts, are of a very handsome appearance, and perhaps might be used as ornamental stones in cases where great strength is not also essential. The general colour of the matrix is pale pink, and the porphyritic felspars are usually rather paler or almost white: some attain a length of 2 in. or even more. Subparallel streaks of black biotite are generally conspicuous. The bands of foliated granite which occur near the head of Loch Luichart, near the railway line, are also in large part composed of augen gneiss, but the crops are much narrower than that at Inchbae, and break along joints into smaller blocks. C. T. C., C. B. C.

WATER SUPPLY AND WATER POWER.

In the sparsely populated hill country which forms most of the map, an ample supply of good water from burns or springs can nearly always be obtained without difficulty. In the lower, more thickly populated Old Red Sandstone tract near the eastern margin it is not so easy to obtain an ample supply.

On the north-west face of Ben Wyvis, above Garbat, there are copious springs, which furnish a supply to the towns of Strathpeffer and Dingwall (both in one-inch map 83), and also some water to provide power for the Electric Lighting Scheme for these places.

The supply for the village of Evanton is obtained from a strong spring, coming apparently from the pebbly sandstones of the Old Red Sandstone, near Assynt House, about a mile north-west of the village. Both quality and quantity are said to be excellent, and there is a large overflow above what is used.

The supply for Alness is believed to be chiefly from small springs. It is understood that a scheme for obtaining a further supply in conjunction with Invergordon is under consideration. The superficial deposits in the neighbourhood of the village belong partly to the 85-foot raised beach and partly to glacial sands and gravels forming mounds and ridges above the level of 85 ft. In these glacial sands on the east of the village various wells have already been sunk for local use. Glacial sands and gravels also form a considerably higher tract, much of it above the 400-foot contour, between Stittenham and Loch Achnacloich. An excellent well is found in this tract close to Achnacloich Castle, and perhaps others could be obtained by sinking further to the west.

In recent years attention has been turned to the possible sources of water power in the Highlands. As already intimated, some of the water from the springs on the north-west face of Ben Wyvis is used in developing power for an Electric Lighting Scheme for Strathpeffer and Dingwall and one or two private establishments. Most of the water for this scheme is, however, obtained from the Rogie Burn (Allt Gleann Sgathaich) near the southern margin of the map. A small reservoir is fed from the burn, and supplies water by a 13-in. steel pipe about three-quarters of a mile long, which gives a fall of 600 ft. In this way a lighting load equivalent to about 250 H.P. can be obtained. The power is transmitted about 13 miles by overhead mains at a high voltage. It is stated that this was the first installation in Great Britain to employ so high a fall, or to transmit power overhead at so high a voltage for so long a distance.*

Some information about the rainfall in the district has been given in Chapter I., but there is great need of more rain-gauge stations, particularly in the north-western portion. Mr. A. Newlands, C.E., has lately calculated the possibilities of obtaining power from various Highland lochs and rivers.† He states that Loch Glass, with a drainage area of 26 square miles and an elevation of 716 ft., is capable, in a 300-foot fall, of developing 600 H.P. continuously. Such a fall could be procured at a distance of about three miles and a quarter from the foot of the loch. If the power were not used for all the twenty-four hours its amount would be increased proportionately. Mr. Newlands also states that Loch Luichart, with a drainage area of 145 square miles and at a height of 250 ft., could, in a fall of 100 ft., develop 1240 H.P. continuously. This fall could be got about a mile from the outlet of the loch, in one-inch map 83. C. T. C., L. W. H.

* The above particulars have been kindly supplied by Major E. W. Blunt-Mackenzie of Castle Leod.

† 'The Possibilities of Power from Highland Lochs and Rivers,' *Inverness Courier*, 24th and 27th November 1908.

APPENDIX.

I. LIST OF OLD RED SANDSTONE FISHES FROM EDDERTON.

The following Old Red Sandstone fossil fishes, named by Dr. R. H. Traquair, have been collected by Mr. D. Tait on the south-east bank of the stream two and a quarter miles W.S.W. of Edderton Church. The locality is within Sheet 94, but only about 100 yds. east of Sheet 93 :—

Diplacanthus striatus Ag.
Cheiracanthus murchisoni Ag.
Pterichthys productus Ag.
Coccosteus decipiens Ag.
Diplopterus agassizi Traill.
Osteolepis macrolepidotus Ag.
Cheirolepis trailli Ag.
Gyroptychius microlepidotus (Ag).

From the same locality *Pterichthys milleri* Agassiz is also recorded by Dr. Traquair in the " Vertebrate Fauna of the Moray Basin " (Messrs. Harvie-Brown and Buckley), vol. ii.

It may be mentioned that *Psammosteus taylori* Traq. is also recorded in the work just referred to (p. 260) from beds at Balnagown Castle, Kildary (Sheet 94). This fossil is ascribed by Dr. Traquair to the Upper Old Red Sandstone. It is probable, therefore, that the limits of this formation extend further south than is shown in the published copy of that geological Sheet.

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EXPLANATION OF PLATE IX.

PHOTOMICROGRAPHS OF SEDIMENTARY ROCKS FROM THE VICINITY OF THE AUGEN GNEISS.

FIG. 1. *Garnetiferous biotite hornfels* (× 8), 10954, 666 yds. from Mullach Creag Riaraidh, between N.E. and E.N.E. The photograph shows a pebbly band alternating with fine argillaceous layers. The pebbles are nearly all quartz, and preserve well their original rounded forms. Bedding is indicated in the argillaceous part of the rock by seams of quartzose or arenaceous composition and fine bands of argillaceous matter, densely filled with minute scales of biotite.

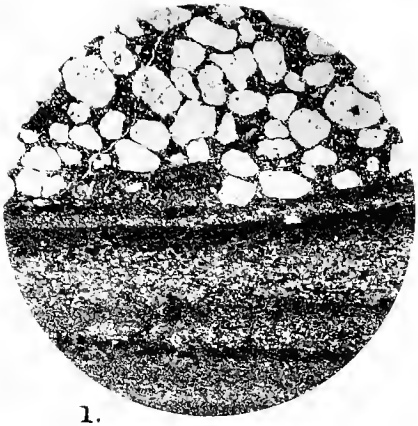
FIG. 2. *Garnetiferous biotite hornfels* (× 10), 11797, Salachie Burn (Garbh Allt), about a mile south-east of Glen Calvie Lodge. In this rock the original bedding is visible as the alternation of fine argillaceous and coarser-grained arenaceous bands of sediment. Much biotite has been developed by the thermal action of the granite gneiss, and small garnets appear as dark spots scattered through the slide.

FIG. 3. *Stippled schist*, same locality as above (× 10), 11801. This presents an early stage of foliation; the quartz and mica are more coarsely crystalline than in the hornfels, the bedding is less obvious and the mica flakes have an orientation which indicates incipient foliation. The garnets have inclusions arranged in spirals (see Fig. 6).

FIG. 4. *Garnetiferous mica schist* (× 10), 12682, on hillside ¾ mile south-west of Glen Calvie Lodge. This photograph has been taken with the same magnification as the two preceding ones, and shows the continued growth in size of the mineral particles and the progressive development of foliation in the rock. The constituent minerals are quartz, black and white micas and garnet.

FIG. 5. *Chiastolite slate* (× 28), 10955, loose piece about 3 miles south-east of Lochan a' Chairn. The chiastolite retains perfectly its rhomboidal outlines, but its interior has been entirely converted into prisms of kyanite, arranged in divergent bunches; a white outer zone consists of scaly muscovite. The external surface of the crystal has a dark coating of iron oxides and graphite.

FIG. 6. *Garnet crystal* in stippled schist (× 48). This is an enlarged view of one of the garnets in Fig. 3, showing the spiral arrangement of the dark inclusions.



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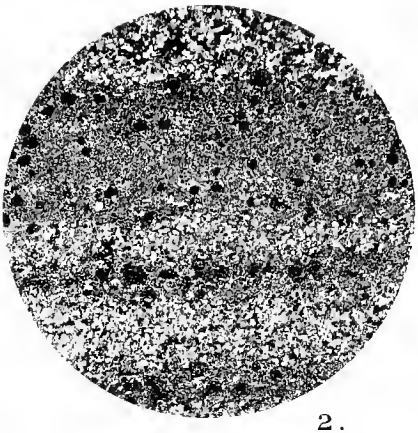

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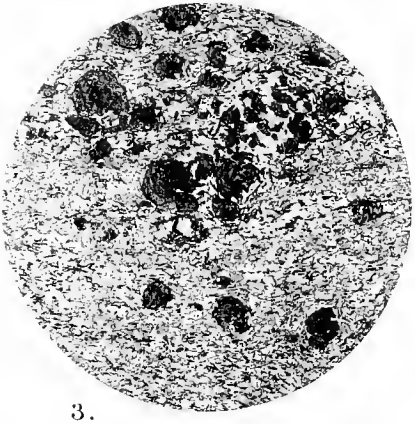

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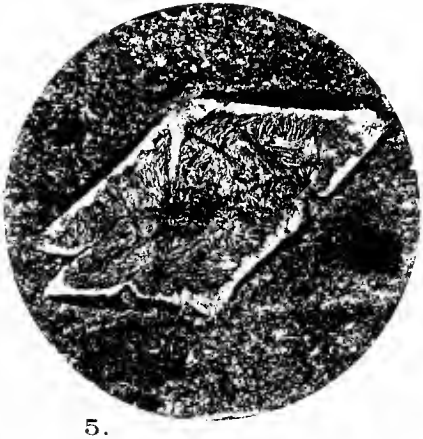

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PHOTOMICROGRAPHS.

EXPLANATION OF PLATE X.

PHOTOMICROGRAPHS SHOWING DEVELOPMENT OF SCHISTS FROM IGNEOUS ROCKS.

FIG. 1. *Lamprophyre* (vogesite) (× 33), 12375, from the burn ¼ mile N.N.W. of outlet of Loch Bad a' Bhathaich. This is one of the sheared lamprophyres, but its igneous structures are not greatly modified. The large crystals of hornblende are being replaced by crystals of biotite that lie parallel to the prism faces of the amphibole. The matrix consists of slightly crushed felspar with needles of apatite and grains of carbonates.

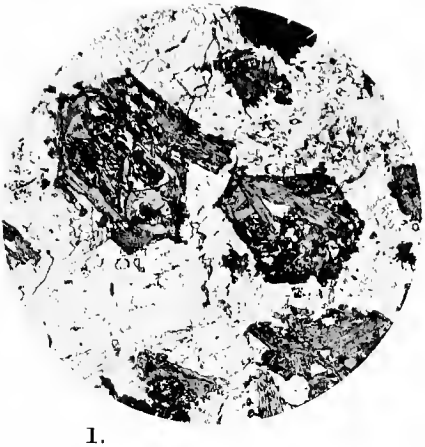
FIG. 2. *Lamproschist* (× 20), 11800, from a sill in a thrust plane in Salachie Burn (Garbh Allt) about a mile south-east of Glen Calvie Lodge. A perfect schist with folia of dark green hornblende and biotite and white streaks of felspar and carbonates.

FIG. 3. *Amphibolite* (× 20), 9864, between Kinloch and Meall an Tuirc. A foliated rock though of rather massive type. It consists of brownish-green hornblende, felspar, iron ores, epidote and sphene.

FIG. 4. *Calc-biotite schist* (× 10), 10377, 4000 ft. S.S.W. of Bodach Mor. A highly foliated schist consisting of brown biotite, quartz, carbonates and epidote. This type of orthoschist occurs at the margins of the epidiorite sills, where they have been greatly sheared.

FIG. 5. *Epidiorite* (× 35), 10960, 1433 yds. slightly west of south of Ordnance Station 2080 ft. on Carn Bhren. An epidiorite developed from a dolerite and still showing remains of ophitic structure. The felspars, partly idiomorphic, are enveloped in masses of dark green hornblende that have been formed from the original augite of the rock.

FIG. 6. *Biotite hornblende schist* (× 26), 12680, dyke above the rock pinnacle on the south side of Glen Diebidale, rather more than a mile S.S.E. of Diebidale Old Lodge. This illustrates the structure of the dolerite dykes that have been greatly sheared in the later crush zones in the augen gneiss. It is well foliated, and the principal minerals are green hornblende, biotite, felspar, quartz and iron oxides.



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PHOTOMICROGRAPHS.

EXPLANATION OF PLATE XI.

FIG. 1. *Porphyritic granite* (× 3½), 12380, near top of Carn Cas nan Gabhar. This is a coarse-grained rock, photographed with a very low magnification, and shows idiomorphic felspar phenocrysts and large grains of quartz, in a granitic matrix that is almost unsheared.

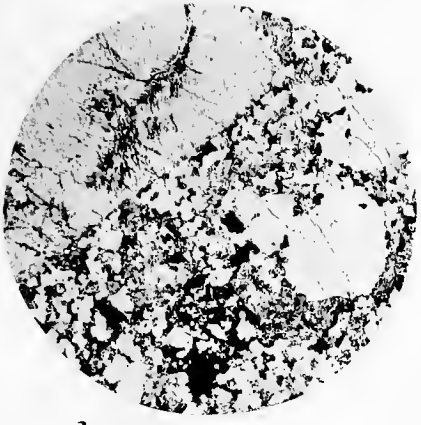
FIG. 2. *Ægirine riebeckite gneiss* (× 22), 10873B, Carn Chuinneag, at Ordnance Station 2749 ft. The dark crystals are ægirine, riebeckite and magnetite, and the clear matrix is alkali felspar and quartz; the foliation of the rock is clearly shown.

FIG. 3. *Albite gneiss* (× 11), 11796, lower tinstone belt, north-west shoulder of Carn Chuinneag. The large clear grains are rounded albites, and the matrix between them is rich in green biotite.

FIG. 4. *Magnetite-cassiterite block* (× 20), 11233B, found loose 1100 yds. slightly south of east of Ordnance Station 1692 ft. on Mullach Creag Riaraidh. Scattered through a black mass of magnetite are many crystals of cassiterite showing dark centres and paler outer zones. This block is exceptionally rich in tinstone.

FIG. 5. *Epidiorite* (× 46), 11790, 783 yds. slightly east of north of Carn Dubh. Epidiorite developed from gabbro, a basic member of the plutonic series that includes the augen gneiss. The felspars partly retain their idiomorphic outlines, and traces of ophitic structure are visible in the slide. In the interior of the felspars small grains of epidote have formed, and the iron oxides are bordered with granular spheue.

FIG. 6. *Scyelite* (× 21), 9856, Carn Cas nan Gabhar. Biotite appears on the left, and on the right a large hornblende crystal enclosing decomposed olivine. The biotite is surrounded by grains of olivine changing to serpentine and magnetite.



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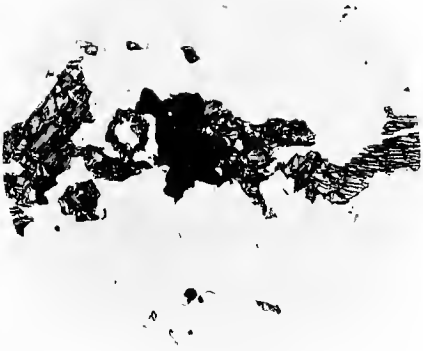

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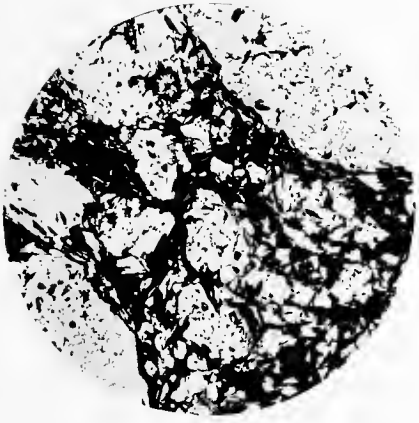

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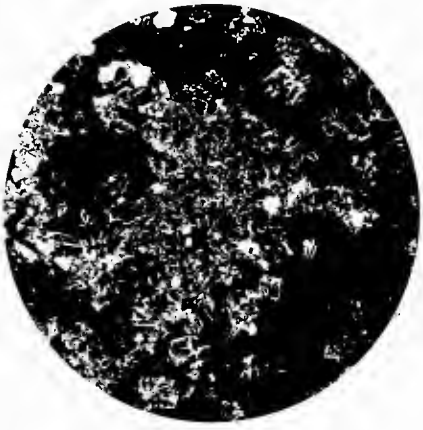

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